KTH Industrial Engineering and Management

Hybrid Power System for Eluvaithivu Island Sri Lanka

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ABSTRACT

Government of Sri Lanka has policy target to achieve 100% electrification by end of year 2012. Grid-based electrification is possible up to maximum 95% of the population in Sri Lanka. Balance 5% of the electrification has to be mainly depending on off-grid technologies such as solar PV, wind, biomass and micro hydro.

Use of renewable based off-grid technologies is limited by the seasonal variation of the resource. This barrier could be overcome by coupling renewable based power generation technologies with a diesel generation thereby forming a hybrid power system. Given the comparatively higher investment cost, a hybrid power plant needs to be carefully designed and optimized to generate electricity at competitive prices.

There are some Isolated Islands located in the Jaffna Peninsula (Northern part of Sri Lanka) called Eluvaithivu, Analaithivu, Nainathivu and Delft Islands. These islands are far away from mainland. At present diesel generators are supplying electricity to these islands for limited hours. Electrification rate of these islands are very low due to the Grid limitations. Also cost of electricity generation is very high due to the high diesel price.

The main objective of the present study is “Selection of optimized mix of renewable based power generation technologies to form a mini-grid and to supply reliable, cost effective electricity supply to the people living in Eluvaithivu Island’ and thereby support the 100% electrification target by Govt. of Sri Lanka in 2012.

Data collection, survey has been conducted in the Eluvaithivu Island to find out the status of present system, priority needs, resource data and load data to propose suitable power system for this Island. An extensive analyse was conducted using HOMER software model and the result is presented in the report. Optimum design emerges as a wind-diesel hybrid power system having wind turbines generator, diesel generators, battery bank, converter and a hybrid controller.

The result revealed that the economic viability of the project, in the form of a community owned wind-diesel hybrid power system operated on cost-recovery basis is not feasible. But it is an attractive option for CEB to reduce its long term losses on diesel fuel. In other words, if CEB implement this project, it would be an ideal win-win situation where both the CEB and the island community are benefited.

ACKNOWLEDGEMENT

I would like to sincerely thank to my local project supervisor Dr. A. Atputharajah for his dedicated support and continues guidance from the beginning to complete this thesis study.

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I also have to thank to KTH, Royal Institute of Technology, Stockholm, Sweden, SIDA and ICBT Campus Sri Lanka for giving me an opportunity (Full Scholarship) to follow the M.Sc. in Sustainable Energy Engineering.

Also I take this opportunity to thank all the voluntary engineering professionals, CEB Engineers and ICBT Campus supervisors & coordinators specifically Dr. Primal Fernando & Ms..Shara Osman for their valuable support to complete this final thesis report.

LIST OF ABBREVIATIONS

CEB	- Ceylon Electricity Board
DG sets	- Diesel Generator sets
GDP	- Gross Domestic Product
Govt.	- Government
HOMER	- Hybrid Optimization Model for Electric Renewable
MOP&E	- Ministry of Power & Energy, Sri Lanka
NASA	- National Aeronautics and Space Administration
NPC	- Net Present Cost
Solar PV	- Solar Photo Voltaic
R&D	- Research & Development
SIDA	- Swedish International Development corporation Agency
WTG	- Wind Turbine Generator
RE	- Rural Electrification

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1 BACKGROUND

In November 2004, National Renewable Energy Laboratory (NREL) of USA conducted a training course in Sri Lanka to build the capacity of engineers in the Asian region on design and implementation of hybrid power systems using renewable energy technologies. The course was funded by the USAID within the framework of the SARI-E project. Sixteen participants from Sri Lanka, India and Bangladesh were participated in the course.

Prior to commencement of the course, all participants were requested to bring along with them information pertaining to potential off-grid projects in their respective countries / regions so that these could be used as case studies for analyses during the course. One of the case studies that indicated potential for maturing into a real project is the use of a wind-diesel hybrid power system to provide electricity to the people living in the Eluvaithivu Island situated 20 km west of Jaffna. This project idea was initiated by two participants; Myself and Mr.S.Gnanaganeshan (Area Engineer, Jaffna Area), both working in the Ceylon Electricity Board (CEB).

A team of volunteer Engineering Professionals including myself joint together and prepared a pre-feasibility study report to electrify Eluvaithivu Island using renewable energy technologies. National Renewable Energy Laboratory (NREL, USA) provides technical assistance for this pre-feasibility study. This initial pre-feasibility study was completed in November 2005. USAID shows interest in funding this project. But further activities were abandoned due to war in the Northern Province in Sri Lanka.

Govt. of Sri Lanka has taken action to end the war in year 2009. Then they concentrated on the development of the country through various activities. Government has revised the energy policy and created an attractive tariff system for the renewable based electricity generation. Also they motivated Non-Conventional Renewable Energy (NCRE) to electrify rural locations where grid extension is very expensive.

Again with the guidance of Dr. A. Atputharajah {Head, Department of Electrical and Electronic Engineering, Faculty of Engineering, University of Peradeniya.} and the support of Dr. Mithulan Nadarajah {Senior Lecturer, University of Queensland, Australia.) and an overall supports from a group of volunteer Engineering Professionals I was supervised to prepare a fresh feasibility study report in year 2010.

The knowledge that I have learned through distance KTH MSc program particularly RET and Advance RET courses and the introduction of HOMER software was extensively supported me in preparing the feasibility study report for electrifying Eluvaithivu Island using hybrid power system.
Since I have searched for a topic to do my MSc thesis work, my local and KTH supervisors advised me to expand the above study as my thesis work so that it will be really useful for the real implementation.

I am happy to say that the initial feasibility study report was submitted to the Ministry of Power and Energy (MOP&E), Govt. of Sri Lanka and Ceylon Electricity Board (CEB) for their further study towards implementation. Ministry officers are welcomed this initiative and recently informed us that they have submitted the feasibility study report to various donor agencies and out of them KOICA (Korean International Corporation Agency) is very much interested to fund US$10 Million as grant to install hybrid power systems to all four isolated islands namely Eluvaithivu, Analaithivu, Nainathivu and Delft Islands in Sri Lanka.

2 INTRODUCTION

Rural Electrification (RE) has always been a high priority issue in the political agendas of successive Governments in Sri Lanka. Even though the financial returns of RE schemes are generally low, expenditure on RE is justified as a means of enabling the socio-economic development in rural areas. It is the intention of the Government to achieve a household electrification rate of 100% by the end of 2012 with most rural districts achieving rates above 60%. According to the Ministry of Power & Energy, grid based electrification is unlikely to go beyond 95% due to technical and financial limitations.

It is well known that changing socio-economic conditions in rural areas have created an increasing demand for electricity, mainly for electric lighting and to operate common household electric appliances. To meet this demand, households in un-electrified villages are resorting to renewable energy based off-grid technologies such as solar PV, wind, biomass and micro hydro. Adoption of these technologies is now gathering momentum in Sri Lanka. Given the limitations of grid-based electrification, off-grid technologies might find a growing market in meeting electricity needs of the balance 5% of households.

Application of off-grid technologies has special significance to the northern region in Sri Lanka. There are some Isolated Islands located in the Jaffna Peninsula (Northern part of Sri Lanka) called Eluvaithivu, Analaithivu, Nainathivu and Delft Islands. These islands are far away from mainland (eg: Eluvaithivu – 3.3km), construction of high voltage overhead distribution lines are impossible through the deep sea and installation of submarine cables are very costly. National grid has not yet extended up to Jaffna. At present diesel generators are supplying electricity in these islands for limited hours. Electrification rate, particularly in most of the isolated islands is very low due to the Grid limitations on far distances.

Table 1: Northern Island's electrification status

No	Description	Population (Nos.)	No. of Houses (Nos.)	No. of Electrified Houses (Nos.)	Electrification (%)
1	Eluvaithivu Island	787	110	73	66 %
2	Analaithivu Island	2,324	452	152	34 %
3	Nainathivu Island	3,030	833	520	62 %
4	Delft Island	4,540	1,181	214	18 %

According to CEB engineers in Jaffna, electrification of isolated islands might have to depend on off-grid technologies to a large extent.

Figure 1: Sparsely located isolated islands in northern region of Sri Lanka

Although off-grid electrification was started as pilot projects in early nineties, the technology has now entered the mainstream rural electrification process and has earned recognition in the Government's rural electrification policy. With assistance from the World Bank, the Government has set up a special financing scheme[1] to support widespread adoption of off-grid technologies in un-electrified villages. By the mid of 2010, the cumulative capacity of solar PV systems installed under the RERED[[1]] scheme reached almost 4.7MW, Biomass almost 22kW and micro hydro accounts for about a 1.4MW.

Although current off-grid technologies are largely restricted to micro hydro and solar PV, with the expansion of off-grid electrification there is potential to adopt other technologies such as wind and biomass as well. Use of wind energy for off-grid electrification is, however, limited by the seasonality of the resource. This barrier could be overcome by coupling wind power with a diesel generation thereby forming a hybrid power system. Given the comparatively higher investment cost, a hybrid power plant needs to be carefully designed and optimised to generate electricity at competitive prices.

[1] Renewable Energy for Rural Economic Development (RERED) project administrated by DFCC on behalf of World Bank

3 OBJECTIVE

The main objective of this study is “Selection of optimized mix of renewable based power generation technologies to form a mini-grid and give reliable, cost effective electricity supply to the people living in an isolated island called Eluvaithivu Island located in northern part of Sri Lanka” and thereby support the 100% electrification target by Govt. of Sri Lanka in 2012.

4 METHODOLOGY

Following methodology was used to achieve the main objective.

- List of questionnaires were prepared and the required assessment was carried out among the island society to find out their high priority needs and to verify whether the objective is in line with their high priority needs.

- Detail survey was conducted to collect the details of the existing power system such as capacity, power demand, energy demand, load factor & load profile, distribution system arrangement etc.

- An Excel model was used to predict the future load profile of the future power system. Introduction of energy efficiency measures such as introduction of CFL bulbs to reduce the peak demand & future growth are considered in predicting the future load profile.

- Resource data such as solar radiation, wind data, biomass potential and hydro potential etc at the Eluvaithivu island were collected from various sources and verified.

- Survey was conducted to find out the best renewable based hardware equipment available in the international market and their price & performance. Several preliminary quotations were receives from reputed suppliers for this purpose.

- Detail analysis was conducted to check and verify the performance of the renewable energy conversion devices such as solar PV and wind turbines to select the best suitable equipment for the project.

- Technology options were analyzed using actual cost data of the hardware equipment, resource data and predicted demand data. “HOMER” hybrid power system optimization software was used for the analytical purpose to find out the optimal power system configuration.

- Detail survey was conducted to check and verify the infrastructure facility available for the project such as transport, installation & logistics etc.

- Project costing was done based on the quotation received from the reputed equipment suppliers and based on experience & engineering judgment for the electrification project.

- Detail analysis was conducted to check and verify the Economic viability of the project.

- Emission analysis was carried out to check and verify the environmental effect of this project by comparing proposed power system with the existing diesel generation system.

- An analysis was carried out to check the feasibility of replication of this project idea to the similar locations in the other part of the Sri Lanka.

- Finally listed the conclusion and recommendations.

5 ELUVAITHIVU ISLAND

5.1 General Description

Eluvaithivu is a small island located on the western side of the Jaffna peninsula (Figure 2). The island is oriented in a north-south direction and covers an area of 1.7 km^2. Large part of the island is covered by dense vegetation comprising Palmyra and Coconut palm trees. Island's western side is covered with coral and limestone whereas the eastern side is sandy. Almost the entire Island is underlain with limestone. Due to the sandy surface layer, retention of rainwater is very poor across the island. Although there are 150 hand-dug wells on the island they go dry within a short period after the rainy season causing water scarcity to the people for long periods. Agricultural activities on the island are restricted to the rainy season only.

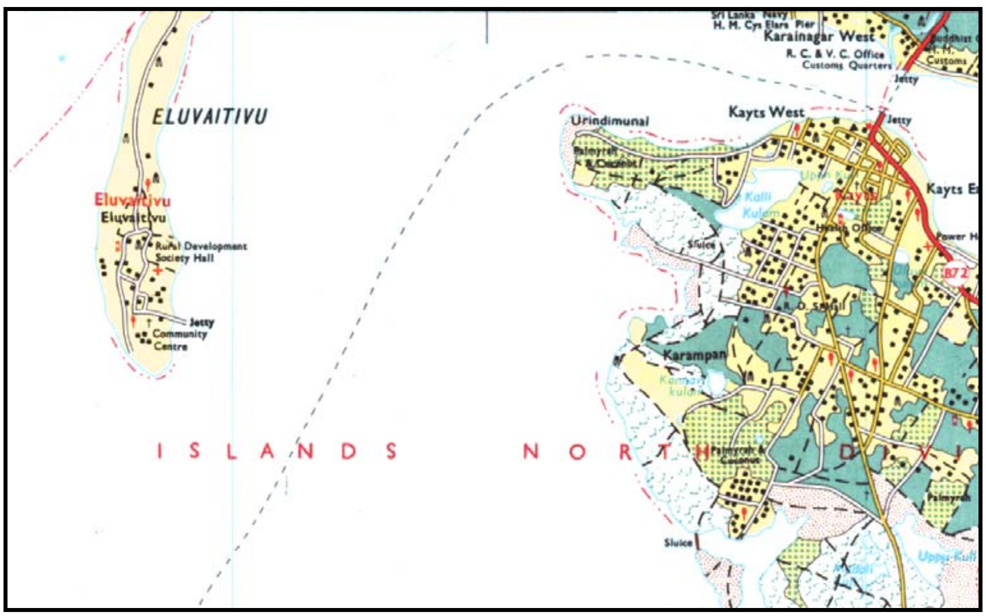


Figure 2: Eluvaithivu island location

Population in the island is 787 persons belonging to 185 families living in 110 houses. Employment status of the families is presented in Table 2.

Table 2: Island community employment status

Occupation	%
Fishing	57.8%
Agriculture	6.0%
Tree tapping	4.8%
Government Employee	0.6%
Traders	1.2%
Miscellaneous	7.2%
Unemployed	22.3%
Total	100%

During a participatory need assessment, the island people have ranked their needs as presented in Table 3.

Table 3: Needs priority list of Eluvaithivu island community

Need	No. of Votes	Ranking
Medical facilities – Buildings	129	1
Extension of electricity supply	104	2
Drinking water	94	3
Ice-Plant /Cooler facility to preserve fish	78	4
Vocational training for youth	34	5
Improvement to internal lanes	27	6
Common Hall (Secretariat / Complex)	24	7
Circuit bungalow for Govt. offices	22	8
Improvements to playground and supply of sports equipment	22	8
Rehabilitation of pre – school	19	9
Building for MPCS sales outlet	18	10
Market	15	11
Providing marketing facilities for local products	9	12
Revolving loans	5	13
Rehabilitation of pond	1	14

5.2 Climate

The general climate prevailing in the island is very much similar to the overall climatic condition of the northern part of Sri Lanka. The region receives rains mainly during the period from October to December. Rainfall during this period accounts for about 70% of the annual total. A distinct spatial variation is observed in the annual rainfall between the islands and Jaffna peninsula – 1365mm in Jaffna and 835 mm in Nainathivu Island (close to Eluvaithivu). Temperature in the region varies from 28^{o}C in December to 33^{o}C in June.

Several coastal areas in Sri Lanka, including the northern region, experience strong winds during the period of the South-West (SW) monsoon (May to October), and moderate winds during the North-East (NE) monsoon (December – February). As could be seen in Figure 3, this wind pattern persists along the entire northern coastal belt from Mannar to Kankesanthurai.

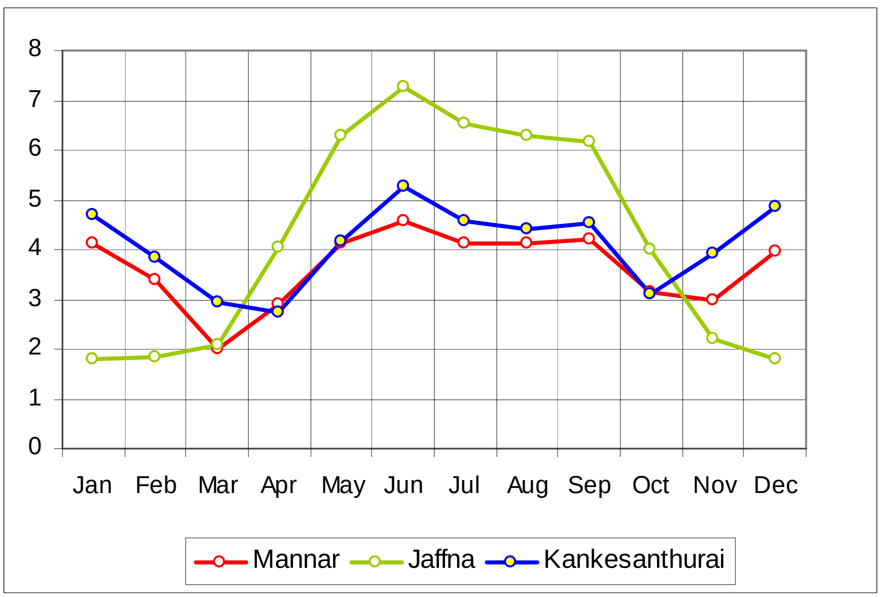


Figure 3: Regional Wind Pattern (Average wind speed is in m/s at 6m height)

There are three meteorological stations in the northern region which have been collecting routine climate data, including surface wind speed. These stations are situated in the Jaffna city, Mannar island and Kankasanthurai. Stations in Jaffna and Mannar are still in operation while the station in Kankesanthurai has been discontinued. Meteorological station in Jaffna collects wind data at three-hourly intervals during the day time by means of a mechanical cup-counter anemometer mounted on a 6 m high mast. The station was originally operated at a coastal location and has been shifted to an inland location during recently past. The coastal location was well exposed to

SW winds, but was shaded from NE winds due to the presence of the Jaffna town. This could be clearly noticed in Figure 3.

Being a small island, Eluvaithivu is well exposed to both monsoons and its wind regime could be better represented by wind data collected in Mannar than those in Jaffna. There are two sources of wind data in the Mannar Island – long-term data collected at the meteorological station on a 6m high mast, and a two-year hourly data set collected by CEB on a 40 m height mast. Latter mast is sited on the coast while mast of the meteorological station is sited in the middle of the town. Monthly average wind data collected from CEB's 40m height mask is shown in Figure 4.

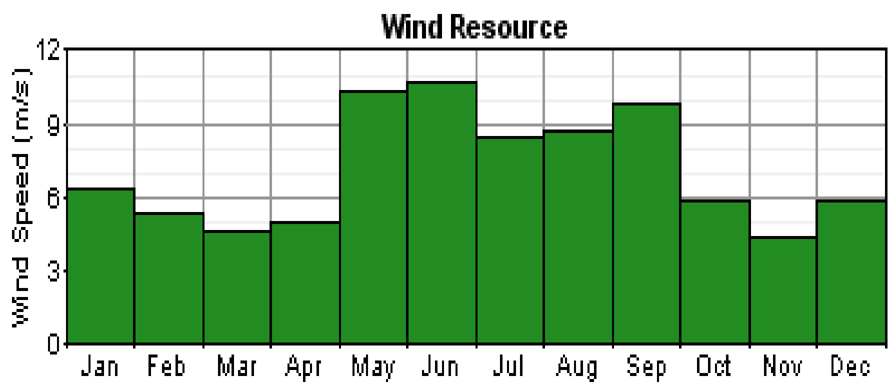


Figure 4: Monthly Wind Pattern in Mannar (Average wind speed is in m/s at 40m height)

Wind resource map for Sri Lanka, developed by National Renewable Energy Laboratory (NREL), USA is given in Annex-1.

Meteorological stations in the northern region do not record solar radiation data. Data sourced from www.eosweb.larc.nasa.gov web site indicate that solar radiation levels are fairly uniform over this region and vary from 4.4 kWh/m^2/day to 6 kWh/m^2/day (Figure 5).

Month	Clearness Index	Daily Radiation (kWh/m2/d)
January	0.552	4.926
February	0.592	5.681
March	0.585	5.994
April	0.554	5.823
May	0.521	5.415
June	0.466	4.774
July	0.465	4.785
August	0.456	4.741
September	0.493	5.063
October	0.484	4.716
November	0.491	4.442
December	0.510	4.424

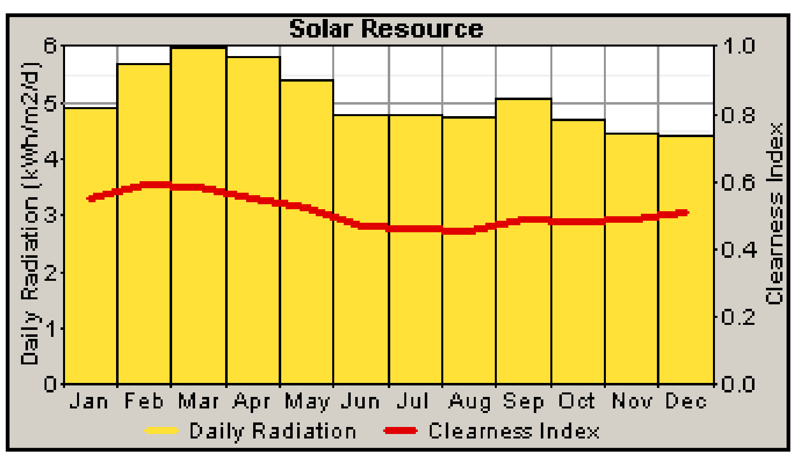


Figure 5: Solar resource available in the island

5.3 Status of Electrification

Currently, the Ceylon Electricity Board supplies electricity to 73 houses in the island using a Diesel Generator set (DG set) of capacity 100kVA. Electricity is made available from 4.30 am to 6.30 am and 6.00 pm to 10.30 pm. Semi annual electricity consumption, as recorded between Jan 2010 and June 2010, amounts to 19,420 kWh. Consumers billed during this period comprise 2 religious institutions, 2 Schools and rest are households. Religious institutions had consumed more electricity supply. However, the monthly consumption in 73 of the households varied between 20 kWh and 40 kWh (Based on detail survey). CEB plans to extend the electricity distribution system to all the houses by the mid of June 2011 and this project is delayed due to consideration of this proposal.

CEB has assigned two operators to the island and these two operators alternately looks after the single Diesel Generator set (DG set) Power Plant in the island. The operators handle regular operation and maintenance of the DG set including starting and stopping of the Generator, fuel supply and regular services including changing of filters and lube oil.

Fuel is transported by boats from mainland to the island in 210 litre barrels. The boat transportation operation is outsourced to an external contractor who charges Rs.500 (US$5.00) per barrel. Up to the jetty of the mainland CEB transports the barrels using their own vehicles and staff.

All the consumers are connected with energy meters and meter reading is carried out in the usual manner. Consumers usually pay their bills to the village post office and the bill payments are at a satisfactory level.

However, the cost incurred by CEB in running the power plant is comparatively high. The old DG set operating in the power plant consumes excessive amounts of diesel and the fact that the DG set is always partly loaded also contributes to the inefficiency. As depicted in Table 4, the electricity generation cost in the island (on average) is above 50 Rs/kWh (US$0.50), while CEB charging a tariff of only US$0.05/kWh. CEB incurs severe financial loss about Rs.1.75 million (US$17,500) every year in operating the existing diesel generator systems in the island.

Table 4: Cost data of present CEB electricity supply to the island

Month	Energy Delivery (kWh)	Fuel Consumption (l)	Av. Fuel Consumption Rate (l/kWh)	Fuel Cost (Rs)	O&M Cost (Rs)	Cost of Electricity (Rs/kWh)	Revenue (Rs)	Loss for the Month (Rs)
Jan-10	3,527	1,454	0.412	130,860	50,000	51.28	17,635	163,225
Feb-10	3,062	1,168	0.381	105,120	50,000	50.66	15,310	139,810
Mar-10	3,499	1,352	0.386	121,680	50,000	49.07	17,495	154,185
Apr-10	3,109	1,260	0.405	113,400	50,000	52.56	15,545	147,855
May-10	2,806	1,235	0.440	111,150	50,000	57.43	14,030	147,120
Jun-10	3,417	1,080	0.316	97,200	50,000	43.08	17,085	130,115
Average	**3,237**	**1,258**	**0.390**	**113,235**	**50,000**	**50.68**	**16,183**	**147,052**

However, with the expansion of existing distribution system to the whole island to provide electricity to all for 24hours, CEB has to bear extremely high financial loss of approximately Rs.12 Million (US$120,000) every year. Further **National Grid expansion to this island using submarine cables is very expensive, since this island is located approximately 3.3kM away from nearest main land.**

5.4 Infrastructure Available for Project Development

Engineering Facilities: Not many large-scale engineering workshops exist in the Jaffna peninsula. Among the workshops surveyed by the study team, only one had facilities that might be suitable for handling the installation of small WTGs and diesel generator sets. The workshop expressed interest in participating in the project as the installation contractor. Following facilities are available:

1. Lathe – 1m bed length
2. Shaping machine
3. Bench drill – 13mm max.
4. Bar cutter
5. Oxy-Acetylene cutter
6. Plasma cutting – up to ¾” steel plate
7. Welding - AC and DC plants – can weld up to 10 mm plates on single side
8. Chain block – 5 Ton (10Ton available in Colombo)

Milling machine is not accessible in Jaffna.

Transport Facilities: Following transport facilities are available in the Jaffna peninsula:

1. 40’ open deck truck (allowable capacity on A9 road is 20 Tons)
2. Undertakes clearing from the port, loading, transportation
3. Boom truck - crane capacity 1.5 Ton, truck capacity 5 Ton

Boat Service to Eluvaithivu Island: A regular boat service is operated between the island and Jaffna mainland by private operators. It is also possible to mobilise a Navy landing craft with a ramp, so that heavier equipment could be landed outside the jetty if necessary

Particulars of the regular boat service are as follows:

1. Length of the boat – 10m
2. Maximum width – 3m
3. The boat is capable of taking 300 bags of cement (50kg each) $\rightarrow$ 15 Ton. However, there is sand accumulation at the Kayts jetty which reduces the available draft. A realistic estimate of the boat capacity is 5 Ton
4. Width of the jetty – 2.5 m

6 ELECTRICITY DEMAND ANALYSIS

In order to design a power system dedicated to Eluvaithivu island, its electricity demand should be estimated correctly. Studying the present supply provided by CEB's diesel generator set is one method of forecasting the probable demand once the proposed power system is implemented. But it should be noted that the present electricity supply is available only for 6½ hours a day and only 73 consumers are connected to the system. However, estimating a demand increase on pro rata basis is also not reasonable since the usage pattern of a curtailed power supply is somewhat distorted compared to the natural utilisation pattern. Therefore the demand data obtained from the present supply system can only be used for indicative purposes.

Table 5 provides the amount of electricity delivered by the existing 100kVA DG set for the 6 months.

Table 5: Electricity delivered by the existing system from Jan'2010 to Jun'2010

Month	Energy delivery (kWh)
Jan-2010	3,527
Feb-2010	3,062
Mar-2010	3,499
Apr-2010	3,109
May-2010	2,806
Jun-2010	3,417

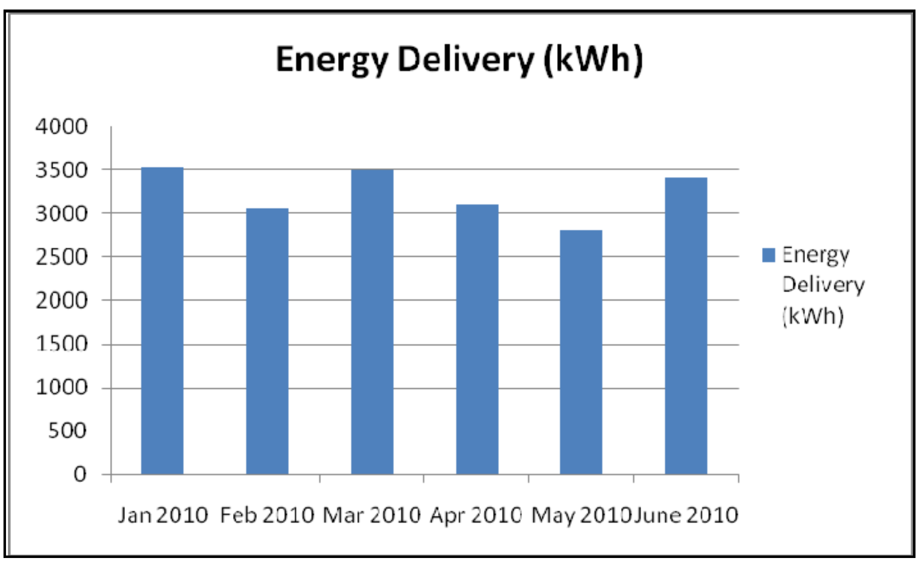


Figure 6: Electricity delivered by the existing system from Jan'2010 to Jun'2010

In addition to energy demand, the capacity requirement or the daily load profile was also analysed. Supply feeder current readings were converted to power readings assuming a 0.90 power factor. Figure 7 illustrate the morning and evening loading levels corresponding to a typical day.

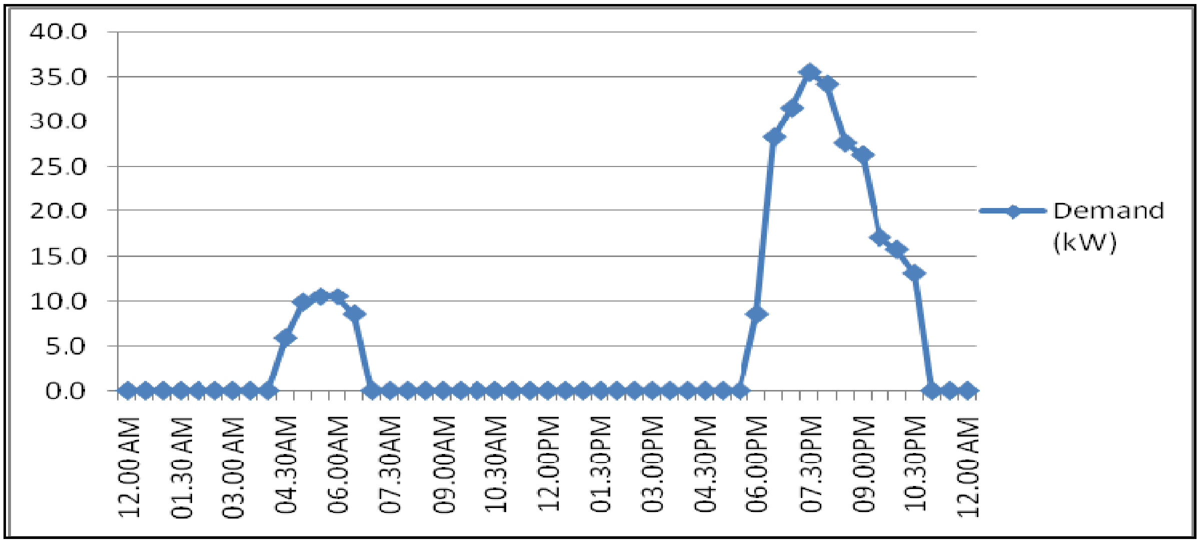


Figure 7: Load profile of existing system

Table 6 provides the conclusions that can be derived by using the demand data of the present supply. The demand scenario for 110 consumers is estimated on pro rata basis taking into account the no. of consumers connected to the present system as 73.

Table 6: Estimation of demand using existing systems data

	Existing System (73 Consumers)	Total Demand (110 Consumers)
Energy (kWh/month)	3,500[[2]]	15,000
Maximum Demand (kW_{Peak})	23	45

Since the island is not 100% electrified at the moment, analysing the present demand profile will merely provide an indication of the demand profile once the power system is commissioned. Therefore, in addition to the analysis of exiting demand, certain estimates regarding electricity utilisation of the villagers also carried out. This was achieved by making use of a software model

[2] Monthly Energy Demand assumed to stabilise at the level achieved by June 2010

which adds up loads of different load categories in the village on hourly basis. However, in estimating the electricity usage of different load categories, demand patterns of villages of this nature as well as some specific behavioural patterns of this island community (ex. early morning fishing related activities) are also modelled. The model used to estimate the village electricity demand as given in Annex 2.

It has also been assumed that energy efficiency measures are also implemented to the extent where the consumer's electricity consumption does not result in high monthly electricity bills creating an adverse impression towards power system. Since lighting will be the highest utilisation application, CFL lamps to be introduced at each household. This would result in a reduced demand and a smaller plant capacity which is very easy to manage, investment wise as well as operational wise. Therefore, the additional effort required to implement energy efficiency measures is reasonably justified.

Figure 8 Shows the estimated community load profile and the demand which has to be met by the power plant including a 10% distribution loss.

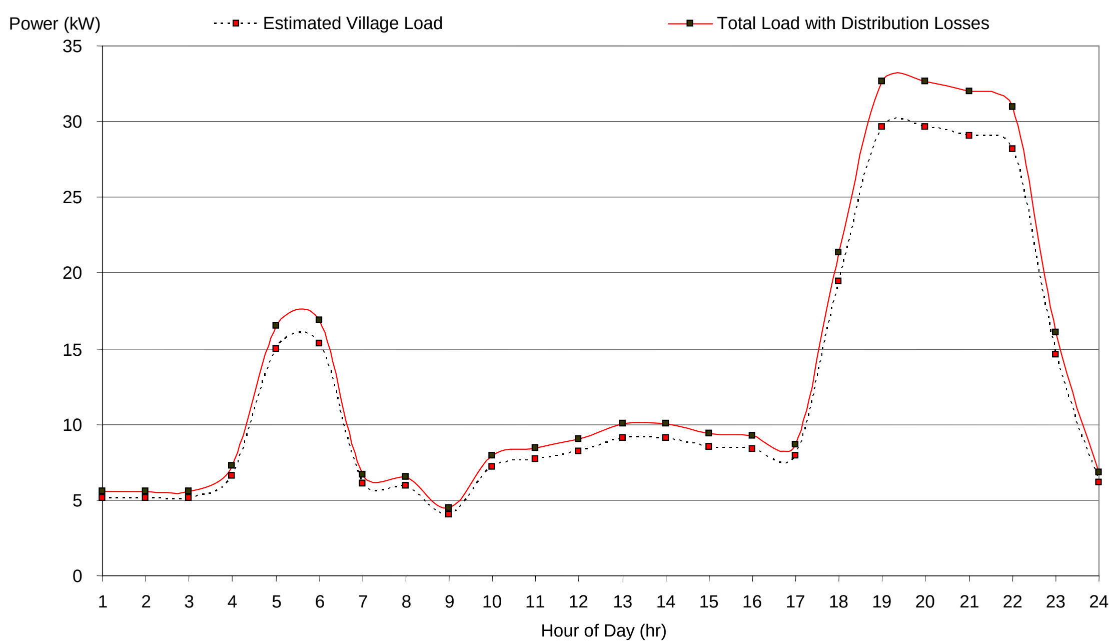


Figure 8: Power plant demand profile (Including distribution losses)

Though the above demand profile is the average demand that shall be met by the power plant, the plant design should cater for occasional demand variations. Also villagers are interested in installing small scale net factory, Ice making machines, coir factory and water desalination plant.

These demands are not known at this stage. Considering all these factors, for power plant sizing and machine selections, the average profile is randomly distributed among the 365 days with an incorporated noise level of 5% (i.e. the standard deviation of daily energy consumption to be 5% around the average figure of 500kWh/day). Similarly, an hourly load variation corresponding to a 10% standard deviation is also assumed. The resultant maximum expected load (or the worst case load) is 44kW. Figure 9 illustrates the load duration curve (no. of hours each load level persists) of the power plant during a year.

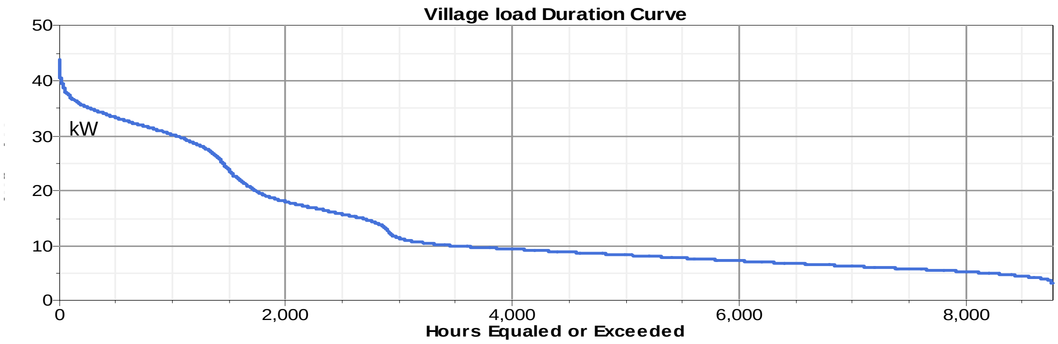


Figure 9: Load duration curve expected to be served by the power plant

7 TECHNOLOGY OPTIONS ANALYSIS

Electricity can be generated from various sources such as Diesel Generators, Solar Panels, Wind Turbines, Hydro Turbine, Biomass Gasifiers and Tidal Wave Generators etc. Out of many options available, some technology options were not considered in this study due to the absence of adequate data and immaturity of technology. Only the following technological options and their combinations were studied in detail to identify the most suitable power system for Eluvaithivu Island.

- Solar Photo Voltaic (Solar PV)
- Wind Turbine Generators (WTG)
- Diesel Generator sets (DG sets)
- Batteries
- Converters
- Hybrid Controllers

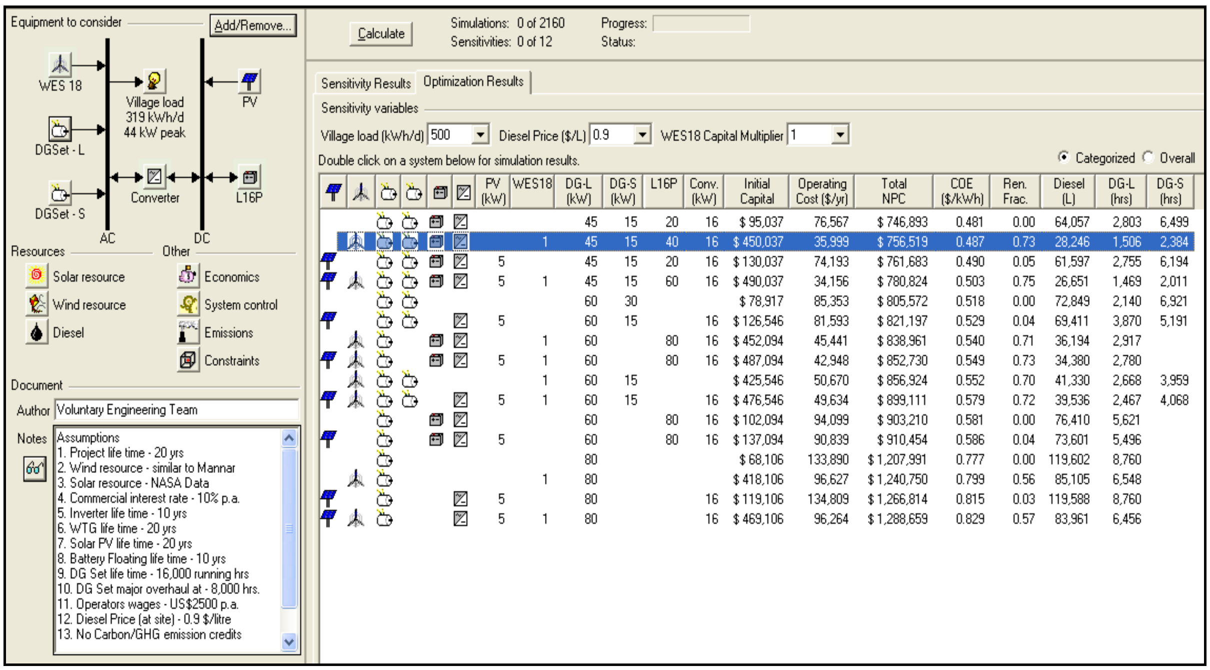
Above technologies can meet the electricity demand of the island, either on their own (ex. diesel only) or by combining with each other (wind-diesel-solar hybrid). However, to determine the best combination out of thousands of available combinations; hybrid system optimization tool 'Homer' was used.

Options Analysis using 'Homer'

Homer is a software tool developed by National Renewable Energy Laboratory of USA (NREL), for the purpose of optimising hybrid power system designs. Extensive analysis is carried out by Homer taking into consideration all the electricity generating options and their operational characteristics, resources and their variations, energy storage, load behaviour and overall control of the system.

Once resource data, load data and power generating equipment data along with the equipment capacities to be considered is given to Homer, It carries out an iterative calculation process and lists the best combinations in merit order ranking them based on discounted lifecycle cost. Obviously, the outputs produced by Homer is directly influenced by the inputs provided to it and the assumptions made in providing these inputs. Therefore, all the inputs (technical as well as economic) given to Homer were either verified by acquiring relevant information from the equipment suppliers or were based on rationale engineering judgements giving due consideration to the context of the project. Assumptions and inputs given to Homer are presented in Annex 3.

Ranking of the technology options based on Net Present Cost (NPC), as analysed by Homer, is presented in Figure 10. The figure shows that two diesel Generators system with battery backup and a hybrid controller is the winning configuration. It is followed closely by a configuration having One WTG with two diesel Generators and battery backup with a hybrid controller. This wind-diesel hybrid system ranks second in the list. NPC of the wind-diesel system is only 1.3% higher than that of the winning configuration. This means that even a modest deviation of the fuel price and/or the wind turbine price from those assumed in the analysis could alter the ranking.



PV (kW)	WES18	DG-L (kW)	DG-S (kW)	L16P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG-L (hrs)	DG-S (hrs)
		45	15	20	16	$ 95,037	76,567	$ 746,893	0.481	0.00	64,057	2,803	6,499
	1	45	15	40	16	$ 450,037	35,999	$ 756,519	0.487	0.73	28,246	1,506	2,384
5		45	15	20	16	$ 130,037	74,193	$ 761,683	0.490	0.05	61,597	2,755	6,194
5	1	45	15	60	16	$ 490,037	34,156	$ 780,824	0.503	0.75	26,651	1,469	2,011
		60	30			$ 78,917	85,353	$ 805,572	0.518	0.00	72,849	2,140	6,921
5		60	15		16	$ 126,546	81,593	$ 821,197	0.529	0.04	69,411	3,870	5,191
	1	60		80	16	$ 452,094	45,441	$ 838,961	0.540	0.71	36,194	2,917	
5	1	60		80	16	$ 487,094	42,948	$ 852,730	0.549	0.73	34,380	2,780	
	1	60	15			$ 425,546	50,670	$ 856,924	0.552	0.70	41,330	2,668	3,959
5	1	60	15		16	$ 476,546	49,634	$ 899,111	0.579	0.72	39,536	2,467	4,068
		60		80	16	$ 102,094	94,099	$ 903,210	0.581	0.00	76,410	5,621	
5		60		80	16	$ 137,094	90,839	$ 910,454	0.586	0.04	73,601	5,496	
		80				$ 68,106	133,890	$ 1,207,991	0.777	0.00	119,602	8,760	
	1	80				$ 418,106	96,627	$ 1,240,750	0.799	0.56	85,105	6,548	
5		80			16	$ 119,106	134,809	$ 1,266,814	0.815	0.03	119,588	8,760	
5	1	80			16	$ 469,106	96,264	$ 1,288,659	0.829	0.57	83,961	6,456	

Figure 10: Technology options ranked according to net present cost (NPC)

If the current trends in the world oil market would continue to persist, there is a strong possibility of further escalation of the diesel fuel price. The prices of wind turbines assumed in the current analysis are based on those quoted by reputed suppliers in the developed countries. Given the technological advances being made in the wind turbines industry in countries like India and China, accessing low-cost wind equipment seems a distinct possibility in the near future. Therefore, a sensitivity analysis was carried out to examine the impact of the price of diesel fuel and WTG on the winning configuration. Variation of the WTG price was modelled in the analysis using a "Capital cost multiplier". Results of the analysis are presented in Figure 11 where the Cartesian space is filled by a colour corresponding to the winning combination.

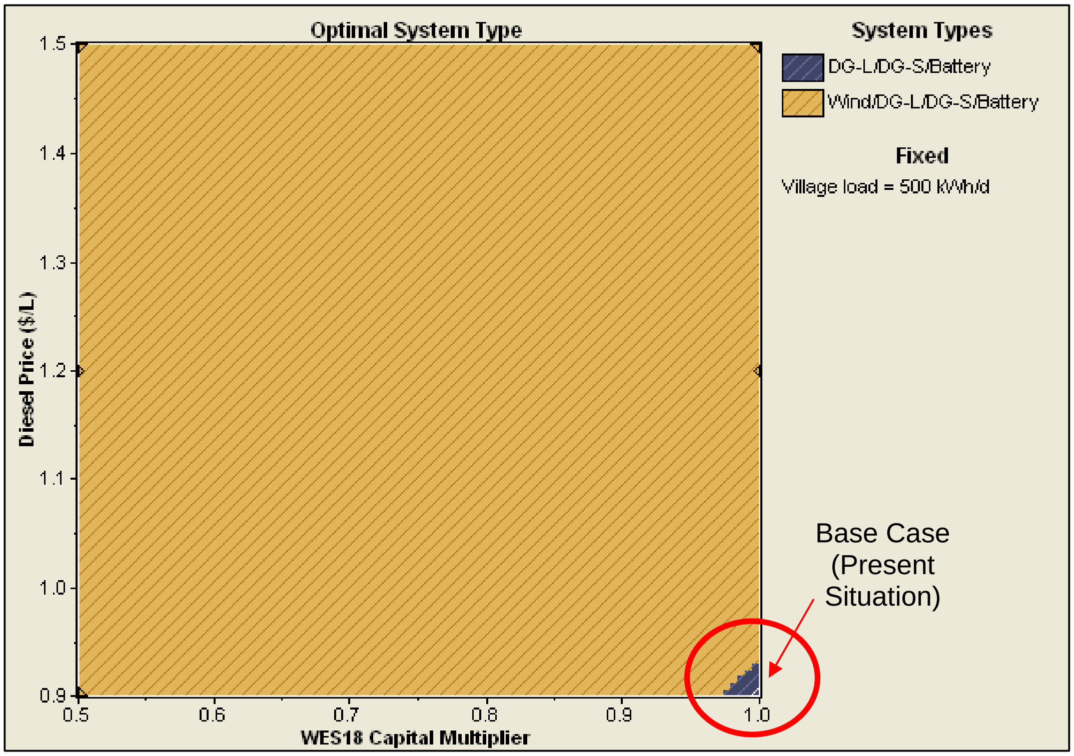


Figure 11: Winning combinations under escalating fuel prices and reducing WTG prices

Figure 11 clearly illustrates that the wind-diesel system analysed in this study would emerge as the winning configuration if the wind turbine price comes down to about 98% of the assumed value even at the current diesel fuel price. Such a reduction of the prices of small wind turbines is a reasonable expectation. Therefore, the prudent decision on equipment selection for this project would be the wind-diesel hybrid system. This selection could be further strengthened by considering the operational cost of the different plant configurations presented in Table 7, Table 8 and Figure 12 which also show that wind diesel hybrid system has the lowest operational cost and also the least effect of escalating fuel price.

Out of different combinations of wind-diesel hybrid systems, the ideal plant configuration would be the system with 1 WTG and 2 DG sets along with converter, battery back-up and hybrid controller (Option 6). This is a high penetration system which also has the flexibility (or certain amount of extra capacity) to meet any unexpected demand increases. For that matter, a demand increase could arise along with the project or even the introduction of an Ice plant, Coir factory, fishing net factory and small water desalination plant which could operate as a deferrable load in the future.

Solar and wind only systems are not attractive enough to merit further study.

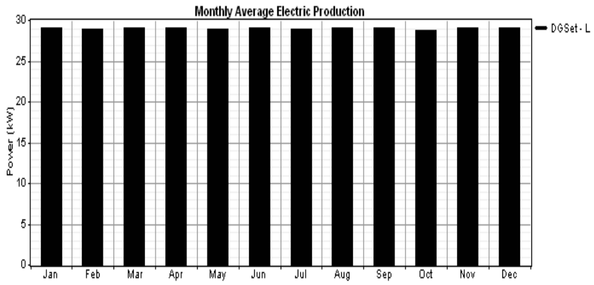
Table 7: Analysis of different combinations of diesel only power systems

Description	Diesel Only Power System					
	Option 1 (1 DG set)		Option 2 (2 DG sets with Hybrid Controller)		Option 3 (2 DG sets with Hybrid Controller, Converter and Battery Bank)	
	Capacity	Cost	Capacity	Cost	Capacity	Cost
WTG (80kW)	-	-	-	-	-	-
DG set (Large)	80kW	$ 18,000	45kW	$ 15,000	45kW	$ 15,000
DG set (Small)	-	-	15kW	$ 10,000	15kW	$ 10,000
Converter	-	-	-	-	16kW	$ 16,000
Battery	-	-	-	-	86kWh	$ 10,000
Hybrid Controller	-	-	-	$ 30,000	-	$ 30,000
Fixed Costs	-	$ 20,000	-	$ 20,000	-	$ 20,000
Contingencies (x %)	-	$ 3,500	-	$ 7,500	-	$ 10,000
Total Project Cost		**$ 41,500**		**$ 82,500**		**$ 111,000**
Cost of Energy ($/kWh)		**0.78**		**0.52**		**0.48**
Renewable Fraction (%)		**0**		**0**		**0**
Operational Cost ($/kWh)		**0.73**		**0.47**		**0.42**
Fuel Cost (Million SLRs/Year)		**12.4**		**7.5**		**6.6**

Table 8: Analysis of different combinations of wind-diesel hybrid power systems

Description	Wind Diesel Hybrid Power System					
	Option 4 (1 WTG & 1 DG set with Hybrid Controller)		Option 5 (1 WTG & 2 DG set with Hybrid Controller)		Option 6 (1 WTG & 2 DG set with Hybrid Controller, Converter and Battery Bank)	
	Capacity	Cost	Capacity	Cost	Capacity	Cost
WTG (80kW)	80kW	$350,000	80kW	$350,000	80kW	$350,000
DG set (Large)	80kW	$18,000	45kW	$15,000	45kW	$15,000
DG set (Small)	-	-	15kW	$10,000	15kW	$10,000
Converter	-	-	-	-	16kW	$16,000
Battery	-	-	-	-	86kWh	$10,000
Hybrid Controller	-	$30,000	-	$30,000	-	$30,000
Fixed Costs	-	$20,000	-	$20,000	-	$20,000
Contingencies (10%)	-	$30,000	-	$30,000	-	$30,000
Total Project Cost (US$)		**$448,000**		**$455,000**		**$481,000**
Cost of Energy ($/kWh)		**0.80**		**0.55**		**0.49**
Renewable Fraction (%)		**56**		**70**		**73**
Operational Cost ($/kWh)		**0.53**		**0.28**		**0.20**
Fuel Cost (Million SLRs/Year)		**8.8**		**4.3**		**2.9**

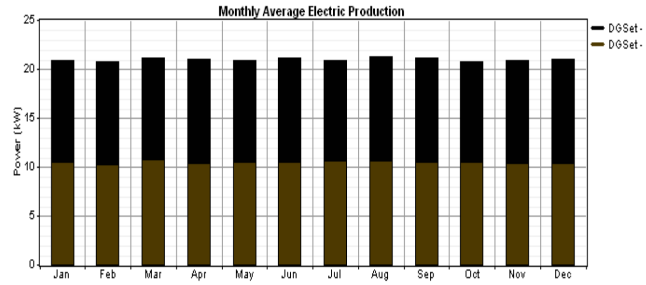
Option 1



Diesel Generator = 254,178 kWh

Diesel consumption per year = **119,602 Litres**

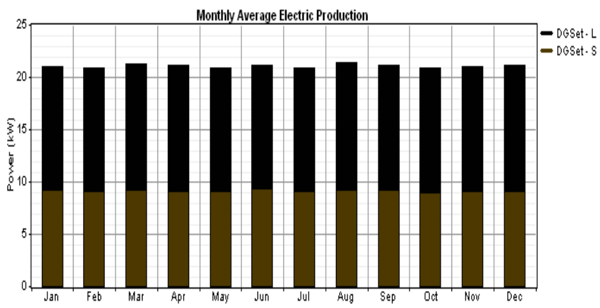
Option 2



Diesel Generators = 183,868 kWh

Diesel consumption per year = **72,849 Litres**

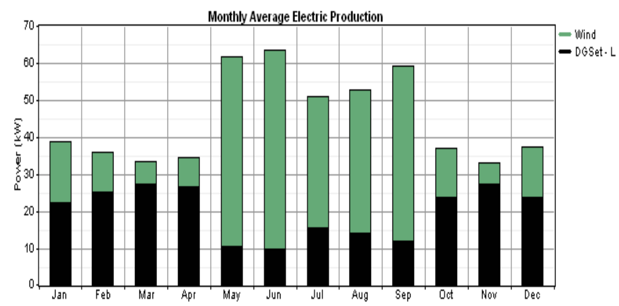
Option 3



Diesel Generators = 184,671 kWh

Diesel consumption per year = **64,057 Litres**

Option 4

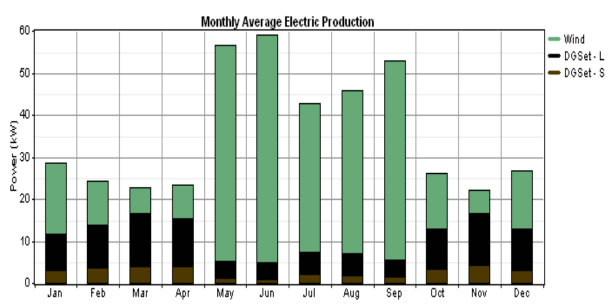


Diesel Generators = 172,810 kWh

Wind Generator = 220,693 kWh

Diesel consumption per year = **85,105 Litres**

Option 5

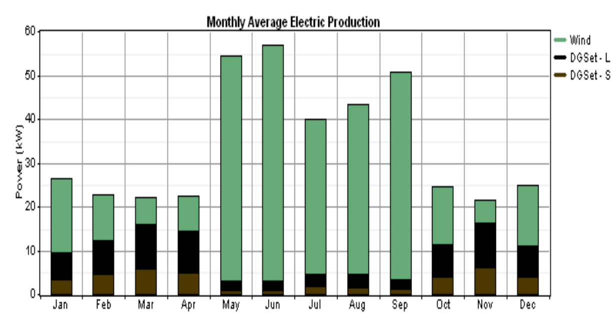


Diesel Generators = 95,091 kWh

Wind Generator = 220,693 kWh

Diesel consumption per year = **41,330 Litres**

Option 6



Diesel Generators = 79,855 kWh

Wind Generator = 220,693 kWh

Diesel consumption per year = **28,246 Litres**

Figure 12: Energy contributions from different sources:

8 PRELIMINARY PLANT DESIGN

Though the required equipment, their sizes and their operating patterns are analysed by Homer, a preliminary technical design of the power plant should also be carried out in order to identify exact issues relating to actual implementation of the power plant project. The schematic diagram (Figure 13) illustrates the basic connections and power flows between constituent components of the power plant.

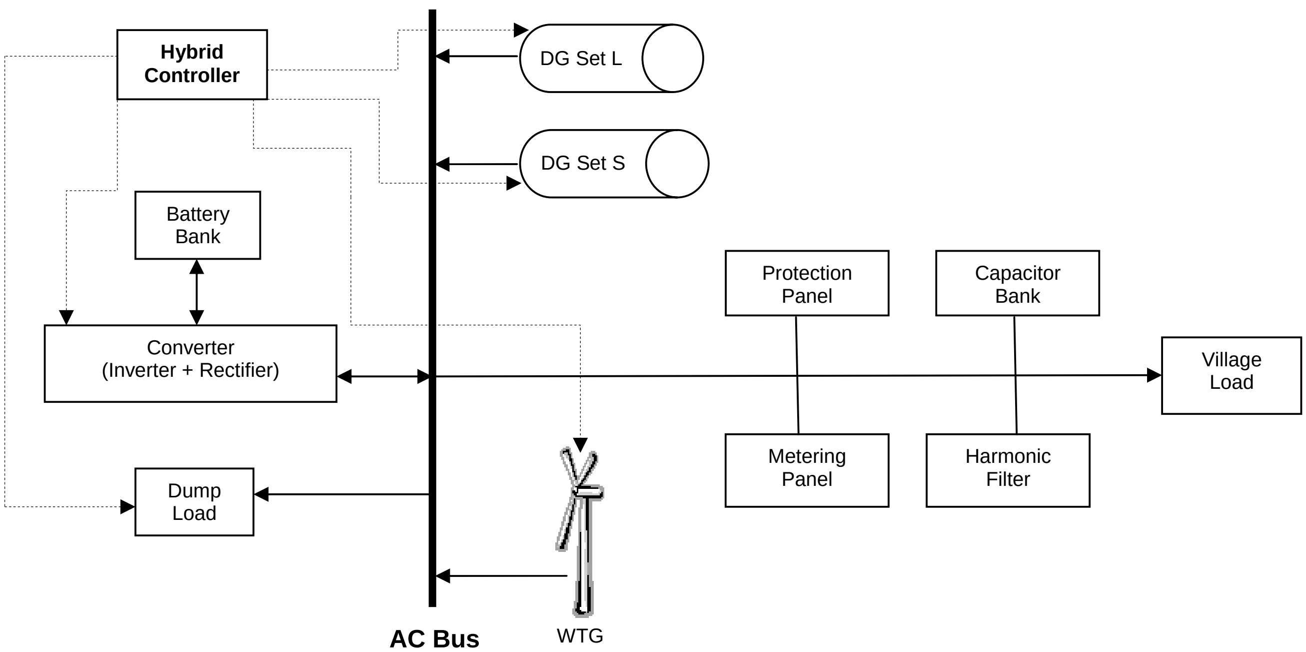


Figure 13: Power plant configuration

As shown in Figure 13, the two DG sets and a WTG will connected to the AC bus bar and will be directly pumping power to the consumers. Batteries are connected to a DC bus which is coupled to the AC bus through a converter (inverter and rectifier) which also includes a hybrid controller, battery charger and a dump load. Therefore the 'Converter' between the two bus bars performs the controlling of the whole system and keeps the whole power system stable under varying generating and load conditions.

Power Plant

The village load which also includes the 10% distribution loss is served by the combination of DG sets, WTG and Battery Bank. Following are the tasks performed by each component of the power plant.

Hybrid Controller: The function of the hybrid controller is to manage the power system in an optimal manner. To achieve this, the hybrid controller is given the control of DG sets, WTG, Converter, the charge controller and the dump load. When wind is available abundantly, the hybrid controller makes maximum use of wind to supply the village load as well as to charge the batteries. However, to make sure that the variation of WTG electrical output and the village load does not affect the system frequency and voltage, the hybrid controller keeps a DG set running most of the times. On the other hand, when wind output is higher than the actual demand, a dump load is switched on to dissipate the excess energy if the battery is full charged at that time. Therefore, the Hybrid Controller effectively maintains the demand - supply balance of the power system in the most economic manner.

DG sets: The two DG sets operate in isolation as well as in synchronism (depending on the requirement) to meet the village load. It also provides energy for battery charging during low wind periods to maintain the battery charge at the desired level. DG sets also perform the critical task of maintaining the frequency and the voltage of the power system using their governor controls and Automatic Voltage Regulator (AVR) units. Due to technical reasons, it is inefficient to operate a DG set at a load level below 30% of its prime rating. Therefore, when the DG sets are running, they will always operate at a load level 30% or more of their prime rating to increase the fuel efficiency and to take-up any variation of village load or wind power/converter output.

DG set’s efficiencies are higher when they are loaded more (70% - 80% of prime rating). Therefore, instead of having a single DG set (which involve a lesser investment), two DG sets of different capacities are used. During low load periods, the smaller DG set is operated and during high load periods, either the larger machine or both machines together are used. This dispatch strategy makes sure that the DG sets are operated at an efficient loading level.

WTG: Wind Turbine Generators are used to utilise the abundant wind resource available in the island to displace part of the electrical energy generated using Diesel Oil. In other words, by retrofitting WTG, the fuel cost is reduced to a certain extent. However, though the operational cost of WTG is negligible, the capital cost is quite substantial and making it uneconomical to use many WTG. Taking into consideration the limitation of land available in the island and the initial investment requirement, it was decided to use 1 WTG of capacity 80kW.

Charge controller and battery bank: A battery bank is used to store the excess energy generated by the WTG and the DG sets in order to harness the most efficient and economical electricity generation available for the power system as and when thus is available and utilise the same when required. The efficient use of batteries is facilitated by providing the Hybrid Controller with the control of the battery charger.

Converter: The converter encloses a rectifier and an inverter which enables energy to flow from AC bus to DC bus and vice versa. The converter type used in this design is a static converter where semiconductor diodes and thyristors perform the relevant conversions with minimum amount of energy losses. Maintenance requirement of these semiconductor devices are minimum and the reliability is also very high, thus making them the obvious choice for this application even with the high initial cost. Here again, there are cheaper converters available in the market which have not proven their performance as yet. But the possibility of using such less costly equipment exists to make the Hybrid Power Systems more economical in future applications.

In addition to these critical components of the power plant, a capacitor bank and harmonic filters are also included in the design. Main reason for including these additional components into the system is to mitigate the impact of harmonics that might be created by the large number of Compact Fluorescent Lamps (CFL) intended to be used in the system (in order to reduce the individual electricity bills of village consumers). In addition, a capacitor bank is also incorporated to the system to maintain the system power factor at a satisfactory level.

9 POWER PLANT LOCATION AND DISTRIBUTION LINES

Power Plant Location and Turbine Siting

To identify the best location to construct the power plant following factors were considered and verified through the villagers.

- Adequacy of space to locate the power plant and the wind turbines
- Wind direction
- Land ownership and existing structures
- Equipment transportation issues
- Distance to main load points
- Operational logistics such as transporting diesel to the power plant

Giving due consideration to all these facts, It is identified that the most suitable place for physically locating the Power Plant is the southern tip of the island (Figure 14) where the Wind Turbines can be sited in such a way that they would face the predominant wind directions of south west and north east without any obstructions from existing buildings or trees. Part of the selected land is private property while the rest is state owned. The owners of the private land have already agreed to donate their land for the power station. The Government Agent (Divisional Secretary) has also agreed to release the state land for this power project. Hence, problems in relation to land acquisition are not perceived. The selected plot of land is in close proximity to the small church building and the fact that there aren't any houses nearby would also simplify construction and operation of the power plant. Also, the power plant site is not far away from the densely populated area of the island and would also reduce the distribution line losses to a reasonable extent.

It is also perceived that the community could be supplied with electricity using the existing distribution line. However, to electrify the whole island, extension of the line is required in some parts of the island. Necessary funding is already available for this line extension project and it is expected that CEB would complete the line extension work prior to the completion of the power plant construction.

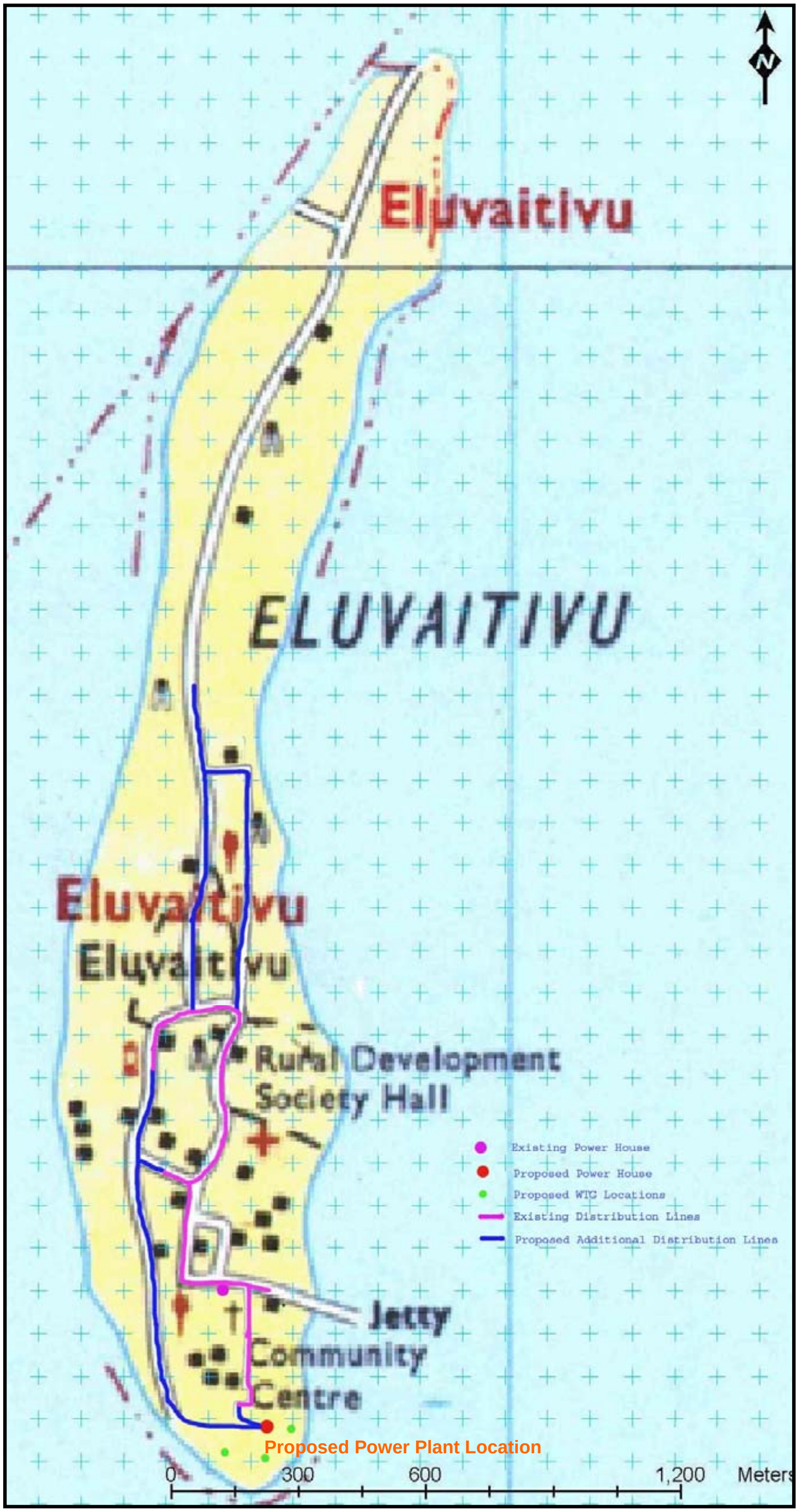


Figure 14: Power plant location and distribution line layout

10 PROJECT COSTS

The cost estimate for the selected power plant configuration is given in Table 9. These cost estimates are based on quotations provided by reputed equipment suppliers and some general cost data relevant to a project of this nature (ex. import tax, transportation, cabling costs etc.). However, these are high end estimates assuming usage of reliable and high quality equipment and workmanship. And the exact prices of equipment and services will vary somewhat once the final design of the power plant is done by the CEB.

Table 9: Cost estimates for the selected power plant configuration

No	Description	Nos./Capacity	Unit Cost (US$)	Total Cost (US$)
1	**Best Option-1:** WTG only (WES18 - 80kW wind turbine with 30M tower and special hybrid controller)	1 Nos. (80kW)	400,000	400,000
	Secondary Option-2: WTG & Solar PV (Gaia-11- 11kW wind turbine with 18M tower and 15kW Grid-Tie Solar PV)	3 Nos.+1No. (33kW+15kW)		
2	Diesel Generator 1	45kW	-	15,000
3	Diesel Generator 2	15kW	-	10,000
4	Converter (Inverter + Rectifier)	16kW	-	16,000
5	Battery Bank	40 Nos. (86kWh)	250	10,000
6	Hybrid Controller	1 Nos.	-	30,000
7	Protection & Metering	Sum	-	15,000
8	Cable termination including cables	Sum	-	15,000
9	Capacitor Bank and Power Quality Filter (Harmonic Filter)	Sum	-	10,000
10	Building for Power House	Sum	-	10,000
11	Project Development & Implementation Cost (CEB)	Sum	-	30,000
12	Contingencies (6%)	-	-	39,000
	Total Project Cost			**600,000**

11 ECONOMIC VIABILITY OF THE PROJECT

As could be seen in Table 7, cost of electricity generated by the selected wind-diesel plant configuration (Option 6) works out to US$ 0.49/kWh, while the operational cost amounts to US$ 0.20/kWh. Based on the CEB tariff charged from presently electrified customers in the island, households pay on average US$ 0.05/kWh. If this power plant proposed as community owned wind-diesel system then the consumers will have to pay almost 4 times the present expenditure on electricity just to meet the operational cost of the proposed wind-diesel plant. Though the wind-diesel system would maintain 24-hour supply of electricity as compared with the limited supply from CEB's diesel generator, it seems most unlikely that the island population would be willing to incur such a high expenditure on electricity. **Thus, the economic viability of the project, in the form of a community owned wind-diesel system operated on cost-recovery basis, would be not viable.**

According to the figures presented in Table 3, the average operational cost of supplying electricity by CEB's existing diesel generator amounts to Rs.50/kWh (US$0.50). Charging a tariff of only US$0.05/kWh, CEB incurs a financial loss of about US$ 17,500 per year in operating the existing diesel generator system in the island. And the loss will further increase with diesel price escalations and increased electrification of the island. In this context, the wind-diesel option with an estimated operational cost of US$ 0.20/kWh has the potential to reduce the financial loss to CEB by about 70%. **Therefore, electrification of the Eluvaithivu Island using a wind-diesel system would be an economically attractive option for CEB. In other words, if CEB implement this project, it would be an ideal win-win situation where both the CEB and the island community are benefited.**

12 ENVIRONMENTAL BENEFITS OF THE PROJECT

As could be seen in Table 10, the emission generated by the Single Diesel Generator power system (Option 1) is almost 4 times higher than selected Wind-Diesel hybrid power system (Option 6). Thus, the proposed power system is mostly environmental friendly power system compared to the existing power system.

Table 10: Comparison of emissions between diesel generator power systems with hybrid power system

No	Description	Single Diesel Generator based power system (1No. Of 80kW DG set)	Hybrid power system with WTG (1WTG, 2DG sets, Battery etc.)	Emission Reduction
	Pollutant	**Emissions (kg/yr)**	**Emissions (kg/yr)**	**(kg/yr)**
1	Carbon dioxide	314,952	74,382	240,570
2	Carbon monoxide	777	184	593
3	Unburned hydocarbons	86.1	20.3	65.8
4	Particulate matter	58.6	13.8	44.8
5	Sulfur dioxide	632	149	483
6	Nitrogen oxides	6,937	1,638	5,299

13 CONCLUSION

The overall study proposes the wind-diesel hybrid power system as the most economical system to electrify the Eluvaithivu Island. The choice of one wind turbine (80 kW) and two diesel generators (45 kW + 15 kW) together with battery energy storage and converter (16 kW) is the most reliable and economical hybrid system to electrify the Island.

The cost of the proposed hybrid power system (option 6) is about 60 million Sri Lankan Rupees. The payback from the fuel saving alone is about 6 to 7 years when compared with the existing diesel based generation technology while providing electricity round the clock to the Eluvaithivu Island.

Table 11: Summary of different power systems configuration

Option	Description	COE ($/kWh)	Renewable Fraction (%)	Operational Cost ($/kWh)	Fuel Consumption (Liters/Year)	Fuel Cost (Million SLRs/Yr)
1	**1 DG Set * (100KVA ~ 80kW)**	**0.78**	**0**	**0.73**	**119,602**	**12.4**
2	2 DG sets	0.52	0	0.47	74,849	7.5
3	2 DG sets & Battery	0.48	0	0.42	64,057	6.6
4	1 DG Set & 1 WTG	0.80	56	0.53	85,105	8.8
5	2 DG set & 1 WTG	0.55	70	0.28	41,330	4.3
6	**2 DG set **, 1 WTG and Battery**	**0.49**	**73**	**0.20**	**28,246**	**2.9**

Note: * - Existing power system
** - Proposed hybrid power system

The economic viability of the project, in the form of a community owned wind-diesel system operated on cost-recovery basis, would be not feasible. Therefore, electrification of the Eluvaithivu Island using a wind-diesel hybrid system would be an economically attractive option for CEB. In other words, if CEB implement this project, it would be an ideal win-win situation where both the CEB and the island community are benefited.

14 RECOMMENDATION

Besides the provision of electricity supply to the island population, the project has the potential to serve the wider objective of demonstrating the feasibility of high penetration wind-diesel hybrid power systems to meet the electricity needs of people in remote and windy regions in Sri Lanka and elsewhere in the developing world. The project could, thus, be a lesson learning experience.

In order to meet this objective, significant volume of additional activities concerning monitoring & evaluation, documentation and dissemination of project experience will have to be incorporated in the project design. As these activities will have to be undertaken in the post-electrification phase, the project life will have to be extended by about 2-3 years after commissioning the power plant. These downstream activities would entail additional costs on necessary equipment, staff, logistics, reporting, publications, seminars, etc. The estimated cost for additional activities concerning monitoring & evaluation is approximately US$50,000.

Further integrating the research and development (R&D) in this project will create professionals with more depth knowledge in this technology to the country. Proper management and development of this research program will lead to produce low cost equipments & components (Such as Hybrid controllers with appropriate algorithm for local needs, Small wind turbines in the order of 10kW etc) which can be manufactured within the country. The local manufacturing process will help to optimize the system to the site requirement, rather purchasing the complete in-built models. Professional involving in the R&D will assist implementing agency (CEB) in modeling optimal power systems, stability studies, preparing specifications, selection of equipment, procurement, installation etc. Also this R&D will enable path to produce more accurate regional wind map of Northern Province to identify the potential locations for future expansion. Therefore integration of a good research program will increase the trend on electrifying other islands with low cost and optimized technologies. Thus the GDP of the country will be lifted up. These R&D activities would entail additional costs works out to US$150,000 on necessary equipment, software, staff, logistics, reporting, publications, seminars, etc.

Key outputs of the project, if it is re-oriented to meet the wider objective, are:

- Analysis of technical performance of the wind-diesel hybrid system.
- Assessment of post-electrification socio-economic changes in the community.
- Validation of performance indicators of the plant as foreseen in the design and optimisation stage.

- Documentation on lessons learnt and wider dissemination of project experience through media, education institutions, workshops, seminars, etc.
- The R&D work through Faculty of Engineering, University of Peradeniya (UOP) will help to develop a low cost locally made hybrid controller (with suitable optimal algorithm) for hybrid power system application in Sri Lanka.
- locally made hybrid controller could be used for other islands electrification projects as well as all micro hydro based RE schemes located mainly UVA/Central/Sabragamuwa Provinces in Sri Lanka. This hybrid power system technique will enable path to accommodate more consumers, approximately 3 fold without much modification in the existing micro hydro RE schemes.
- Testing of two small wind generators of 10kW-20kW range (Grid-Tie model) / Development of locally made small wind generators of 10kW-20kW (Prototype at University) using CAD/CAM technology through the R&D project can be used for other islands electrification projects during expansion to produce low cost electricity with very low capital cost.
- Development of Regional wind map for northern region will be very useful to identify the high wind potential locations for future developments. This can be achieved by installing wind measuring mask at suitable location.
- R&D team will prepare the feasibility study report including detail design for the electrification of other islands such as Analaithivu Island, Nainathivu Island and Delft Island. This will facilitate complete electrification of all these islands at the earliest possible time.

In this context, the project may be treated as a development intervention that might have wider regional impacts and not merely as a project to serve the people of Eluvaithivu Island.

Table 12: Cost estimates for the additional activities

No	Description	Total Cost (US$)
1	Monitoring & evaluation, documentation and dissemination of project experience	50,000
2	Integrating the research and development (R&D) for future expansion	150,000
	Total cost for additional activities	200,000

15 LIST OF REFERENCES

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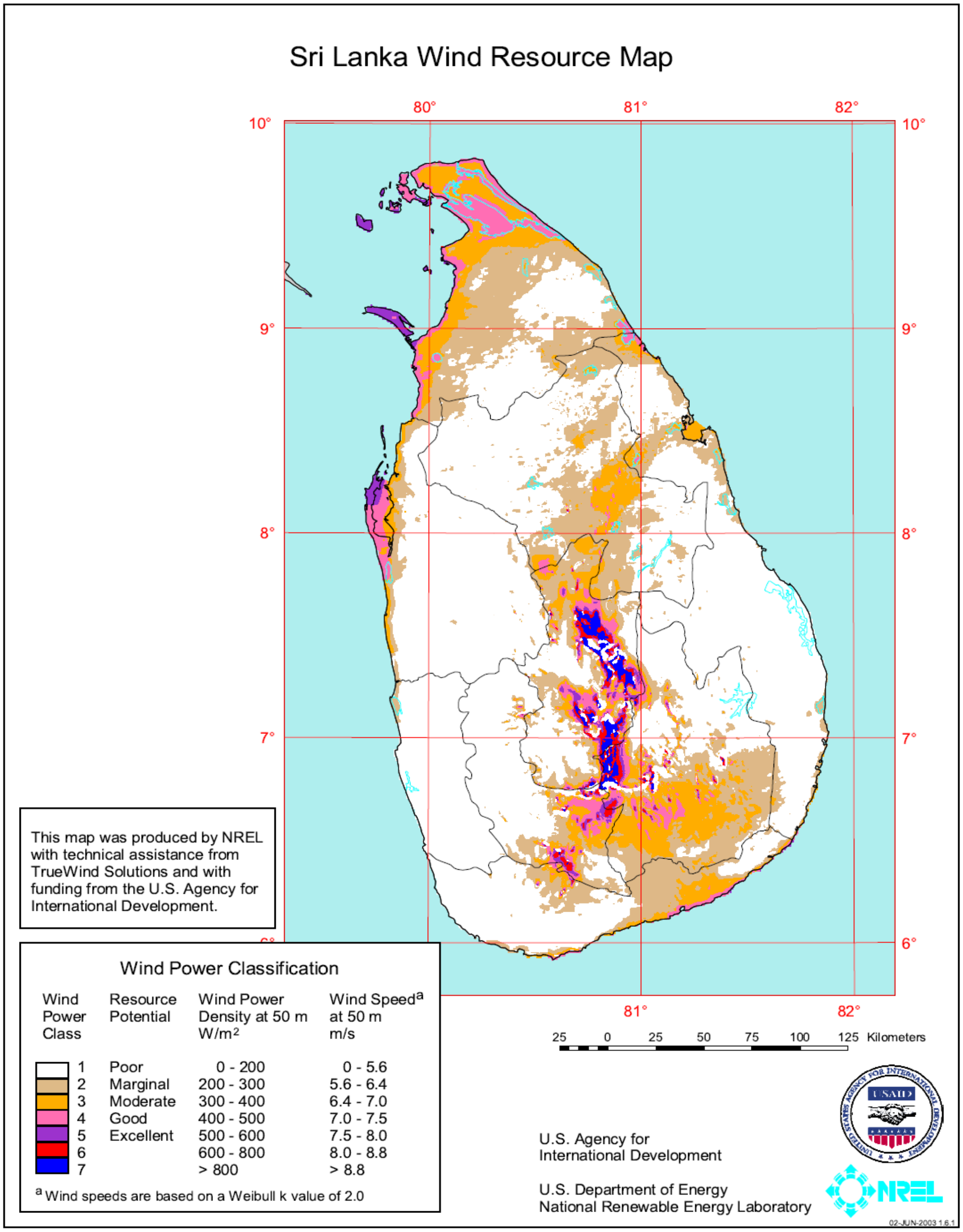
16 ANNEXES

Annex 1: Wind resource map of Sri Lanka



Annex 2: Excel model used for demand analysis

REMOTE COMMUNITY LOAD CALCULATION - TYPICAL DAY PROFILE

Hour of Day

Public Loads			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Hours/day	Wh/day
School																												
User Controlled Loads	Rated Power(W)	Number of Units																										
Fluorescent/incandescent	40	5								1	1	1	1	1	0.8	0.8	0.4	0.4	0.4	0.4	0.4	0.4					9	1,800
CFL	20	6								1	1	1	1	1	0.67	0.67											6	760
fan	100	2								1	1	1	1	1	1	1											7	1,400
Computer	120	5								1	1	1	1	1	1	1	0.6	0.6	0.6	0.6	0.6	0.6					11	6,360
Cooling fan	60	2								1	1	1	1	1	1	1	1	1	1	1	1	1					13	1,560
Total Load (W)										1240	1240	1240	1240	1240	1160	1160	560	560	560	560	560	560						
																											Daily Load (Wh/day)	11,880
Government/Community buildings																												
User Controlled Loads	Rated Power(W)	Number of Units																										
Fluorescent/incandescent	40	2								0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5			1	1	1	1	1	1		10	800
CFL	20	4	0.75	0.75	0.75	0.75	0.75			1	1	1	1	1	1	1	1			0.75	0.75	0.75	0.75	0.75	0.5	0.25	16	1,300
Street lights	20	50	1	1	1	1	1													1	1	1	1	1	1	1	12	12,000
TV	100	3																		1	1	1	1	1	1		6	1,800
Continuous Loads		Duty Cycle																										
Refrigerator	200	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	6	1,200
Total Load (W)			1110	1110	1110	1110	1110	50	50	170	170	170	170	170	170	170	170	50	50	1490	1490	1490	1490	1490	1470	1070		
																											Daily Load (Wh/day)	17,100
Medical center																												
User Controlled Loads	Rated Power(W)	Number of Units																										
Fluorescent/incandescent	40	1				1	1	1												1	1	1	1	1	1	0.5	10	380
CFL	20	4	0.5	0.5	0.5	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	1	0.5	0.5	16	1,280
Fan	100	2	1	1	1	1	1					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	4,000
Radio	15	1					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			18	270
Comunications	5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24	120
Continuous Loads		Duty Cycle																										
Refrigerator	150	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	6	900
Total Load (W)			283	283	283	363	378	178	97.5	97.5	97.5	298	298	298	298	298	298	298	298	378	378	378	378	378	323	303		
																											Daily Load (Wh/day)	6,950
Church and Store																												
User Controlled Loads	Rated Power(W)	Number of Units																										
Fluorescent/incandescent	40	2					0.5	0.5												1	1	1	1	1			6	480
CFL	20	10	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.8	1	1	0.8	0.3	0.3	0.3	8	1,520
Fan	100	1	1	1	1	1	1	1				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21	2,100
Continuous Loads		Duty Cycle																										
Refrigerator	200	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	6	1,200
Total Load (W)			210	210	210	210	250	250	110	70	70	170	170	170	170	170	170	170	170	390	430	430	390	290	210	210		
																											Daily Load (Wh/day)	5,300

Hour of Day

Residential Loads			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Hours/day	Wh/day
House Type 1																												
Number of homes in the community		20																										
User Controlled Loads	Rated Power	Number of Units																										
Fluorescent/incandescent	20	1	1	1	1	1	3	2												3	5	5	5	3	1	1	32	12,800
CFL	40	3				0.25	0.5	0.5												0.25	1	1	1	1			6	13,200
Fan	100	1	0.5	0.5	0.5	0.5	0.5	0.5				0.5	0.5	0.75	0.75	0.75	0.75	0.75	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	12	23,500
TV	100	1						0.5	0.25			0.5	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	1	1	1	1	0.5		12	23,500
Radio	15	1					0.75	0.75	0.75	0.75	0.75	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25		7	2,175
Iron	750	1							0.13	0.13																	0	3,750
Continuous Loads		Duty Cycle																										
Refrigerator	200	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	6	24,000
Total Load (W)			120	120	120	150	231	261	180	155	61.3	154	179	204	204	204	204	204	179	269	424	424	424	384	174	120		
																											Daily Load (Wh/day)	102,925
House Type 2																												
Number of homes in the community		40																										
User Controlled Loads	Rated Power	Number of Units																										
Fluorescent/incandescent	20	4	0.13	0.13	0.13	0.13	0.5	0.5												0.5	1	1	1	1	0.5	0.25	7	21,600
CFL	40	2				0.25	0.5	0.5												0.25	1	1	1	1			6	17,600
TV	100	1						0.25	0.25			0.25	0.25	0.25	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	0.25		9	34,000
Radio	15	1					0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.25	0.25	0.25	0.25	0.25		12	7,050
Total Load (W)			10	10	10	30	91.3	116	36.3	11.3	11.3	36.3	36.3	36.3	61.3	61.3	61.3	61.3	61.3	121	264	264	264	264	68.8	20		
																											Daily Load (Wh/day)	80,250
House Type 3																												
Number of homes in the community		70																										
User Controlled Loads	Rated Power	Number of Units																										
Fluorescent/incandescent	20	3	0.17	0.17	0.17	0.17	0.67	0.67												0.67	1	1	1	1	0.67	0.33	8	32,200
CFL	40	1					0.5	0.5												1	1	1	1	1	1		7	19,600
Radio	15	1					0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75		14	14,963
Total Load (W)			10	10	10	10	71.3	71.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	91.3	111	111	111	111	91.3	20		
																											Daily Load (Wh/day)	66,763

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Total Load	5.1	5.1	5.1	6.58	15	15.3	6.1	5.92	4.04	7.19	7.69	8.19	9.11	9.11	8.51	8.39	7.89	19.4	29.7	29.7	29.1	28.2	14.6	6.18
Distribution Loss	0.51	0.51	0.51	0.66	1.5	1.53	0.61	0.59	0.4	0.72	0.77	0.82	0.91	0.91	0.85	0.84	0.79	1.94	2.97	2.97	2.91	2.82	1.46	0.62
Load to be Served by Power Plant	5.61	5.61	5.61	7.24	16.5	16.9	6.7	6.51	4.44	7.91	8.46	9.01	10	10	9.36	9.23	8.68	21.4	32.6	32.6	32	31	16.1	6.8

Total Daily Village Load (kWh/day)	291.2
Total Monthly Village Load (kWh/month)	8,735

Modified from a spreadsheet designed by Sergio Castedo Sergio Castedo

Annex 3: Technology options analysis - Summary of Homer Inputs

HOMER Input Summary

A3.1 Sensitivity case

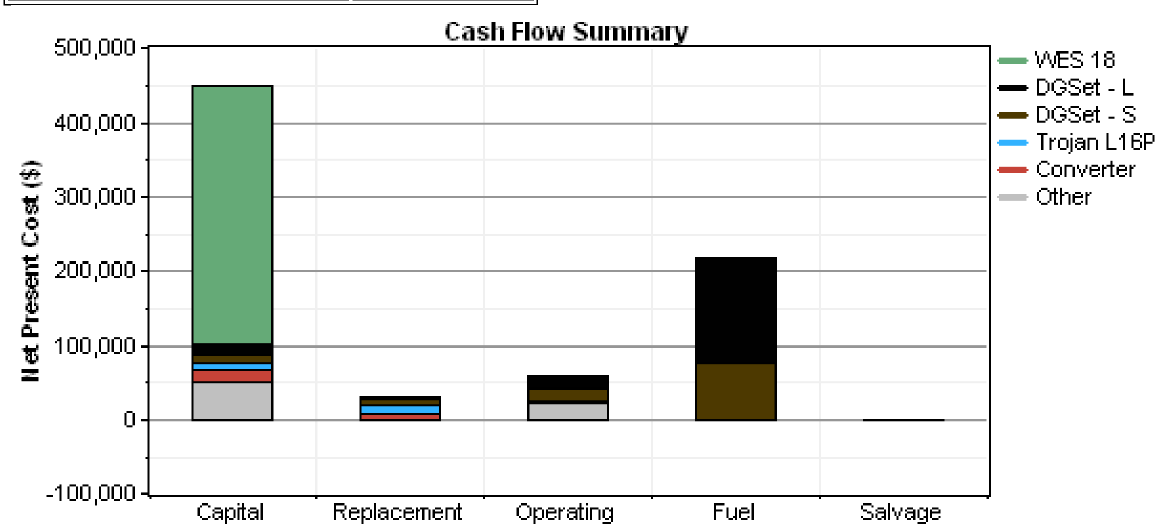
	Village load Scaled Average:	500	kWh/d
	Diesel Price:	0.9	$/L
	WES 18 Capital Cost Multiplier:	1	
	WES 18 Replacement Cost Multiplier:	1	

A3.2 System architecture

Wind turbine	1 WES 18
DGSet - L	45 kW
DGSet - S	15 kW
Battery	40 Trojan L16P
Inverter	16 kW
Rectifier	16 kW
Dispatch strategy	Cycle Charging

A3.3 Cost summary

Total net present cost	$ 756,519
Levelized cost of energy	$ 0.487/kWh
Operating cost	$ 35,999/yr

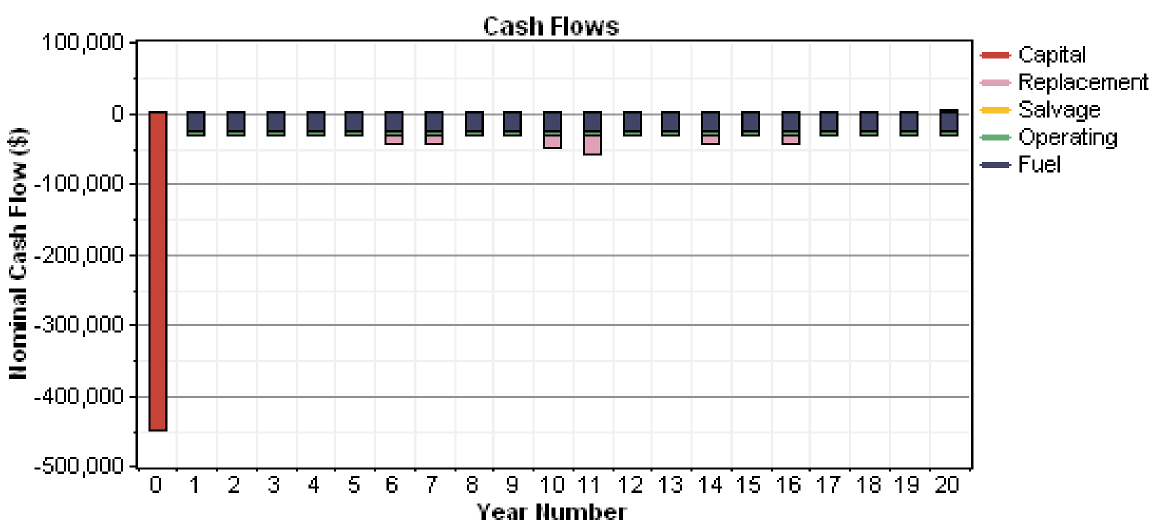


A3.3.1 Net Present Costs

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
	($)	($)	($)	($)	($)	($)
WES 18	350,000	0	851	0	-259	350,593
DGSet - L	14,584	5,298	16,796	140,010	-255	176,434
DGSet - S	9,453	7,616	17,100	76,419	-28	110,559
Trojan L16P	10,000	12,432	1,703	0	-16	24,119
Converter	16,000	6,169	1,362	0	0	23,531
Other	50,000	0	21,284	0	0	71,284
System	450,037	31,515	59,096	216,429	-557	756,519

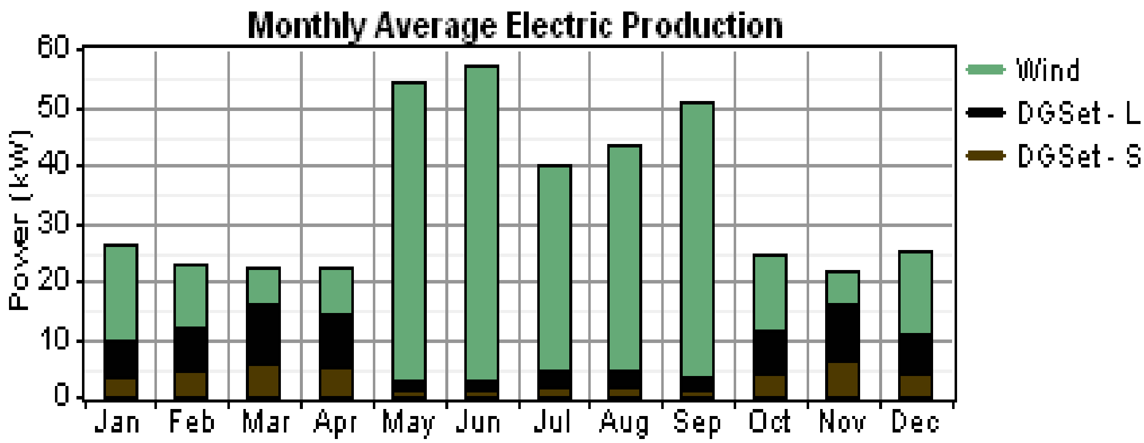
A3.3.2 Annualized Costs

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
	($/yr)	($/yr)	($/yr)	($/yr)	($/yr)	($/yr)
WES 18	41,111	0	100	0	-30	41,180
DGSet - L	1,713	622	1,973	16,446	-30	20,724
DGSet - S	1,110	895	2,009	8,976	-3	12,986
Trojan L16P	1,175	1,460	200	0	-2	2,833
Converter	1,879	725	160	0	0	2,764
Other	5,873	0	2,500	0	0	8,373
System	52,861	3,702	6,941	25,422	-65	88,860



A3.4 Electrical

Component	Production	Fraction
	(kWh/yr)	
Wind turbine	220,693	73%
DGSet - L	51,405	17%
DGSet - S	28,450	9%
Total	300,549	100%



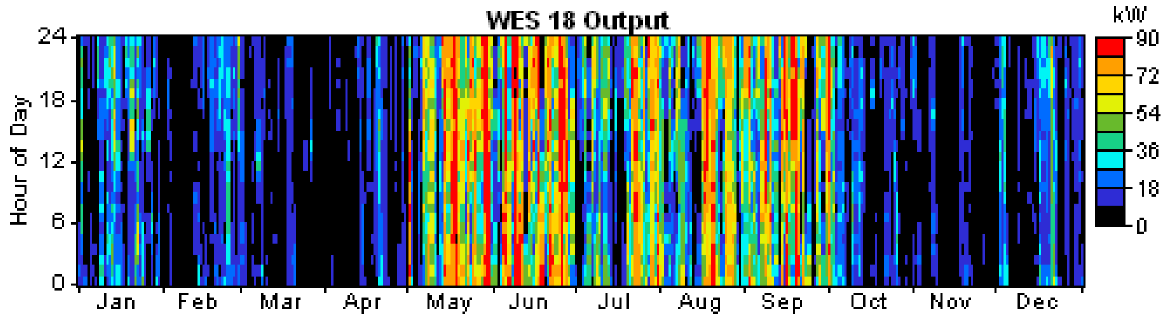
Load	Consumption	Fraction
	(kWh/yr)	
AC primary load	182,500	100%
Total	182,500	100%

Quantity	Value	Units
Excess electricity	114,839	kWh/yr
Unmet load	0.000193	kWh/yr
Capacity shortage	0.00	kWh/yr
Renewable fraction	0.734	

A3.5 AC Wind Turbine: WES 18

Variable	Value	Units
Total rated capacity	0.00	kW
Mean output	25.2	kW
Capacity factor	0.00	%
Total production	220,693	kWh/yr

Variable	**Value**	**Units**
Minimum output	0.00	kW
Maximum output	83.3	kW
Wind penetration	121	%
Hours of operation	8,248	hr/yr
Levelized cost	0.187	$/kWh

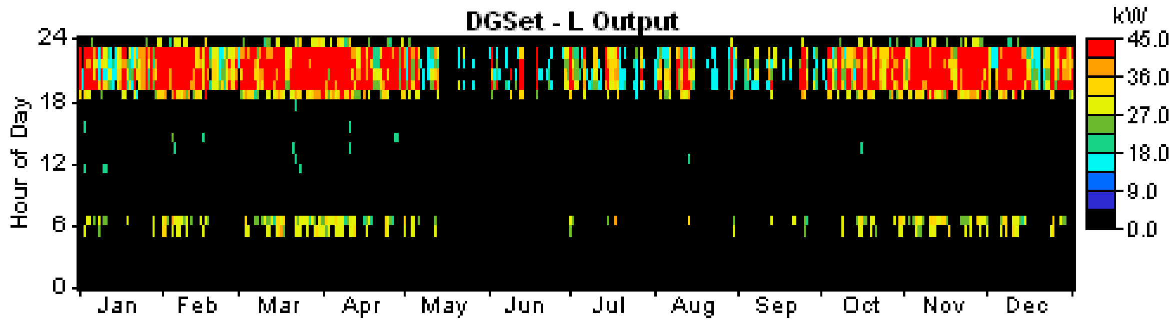


A3.6 Diesel Gen Set – Large

Quantity	Value	Units
Hours of operation	1,506	hr/yr
Number of starts	461	starts/yr
Operational life	10.6	yr
Capacity factor	13.0	%
Fixed generation cost	5.46	$/hr
Marginal generation cost	0.225	$/kWhyr

Quantity	Value	Units
Electrical production	51,405	kWh/yr
Mean electrical output	34.1	kW
Min. electrical output	13.5	kW
Max. electrical output	45.0	kW

Quantity	Value	Units
Fuel consumption	18,273	L/yr
Specific fuel consumption	0.355	L/kWh
Fuel energy input	179,805	kWh/yr
Mean electrical efficiency	28.6	%

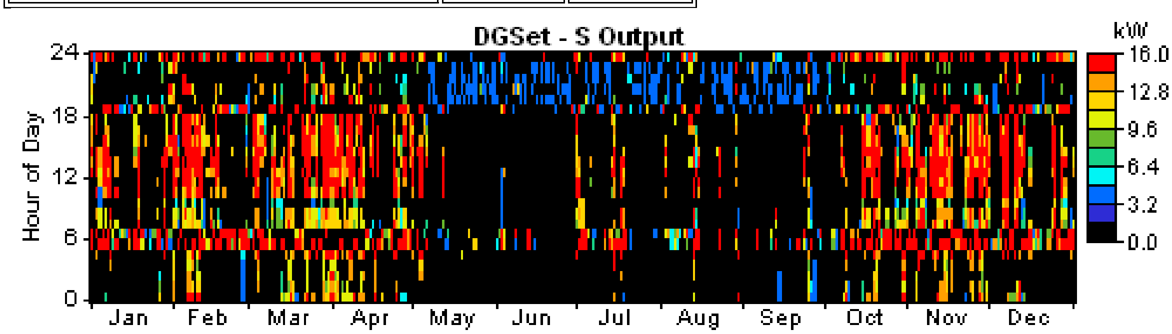


A3.7 Diesel Gen Set – S

Quantity	Value	Units
Hours of operation	2,384	hr/yr
Number of starts	1,027	starts/yr
Operational life	6.71	yr
Capacity factor	21.7	%
Fixed generation cost	2.51	$/hr
Marginal generation cost	0.225	$/kWhyr

Quantity	Value	Units
Electrical production	28,450	kWh/yr
Mean electrical output	11.9	kW
Min. electrical output	4.50	kW
Max. electrical output	15.0	kW

Quantity	Value	Units
Fuel consumption	9,973	L/yr
Specific fuel consumption	0.351	L/kWh
Fuel energy input	98,139	kWh/yr
Mean electrical efficiency	29.0	%

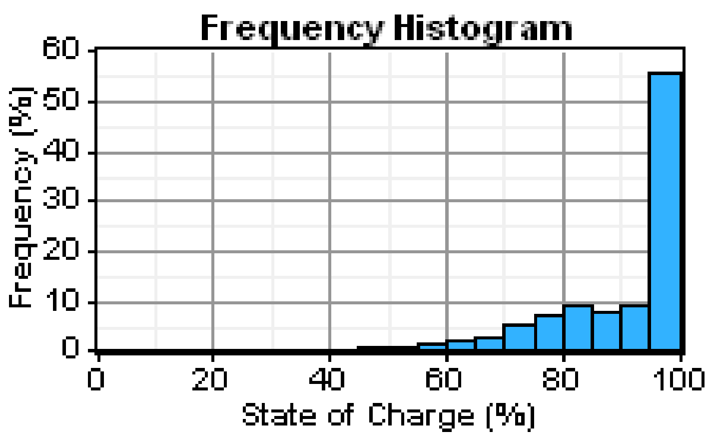


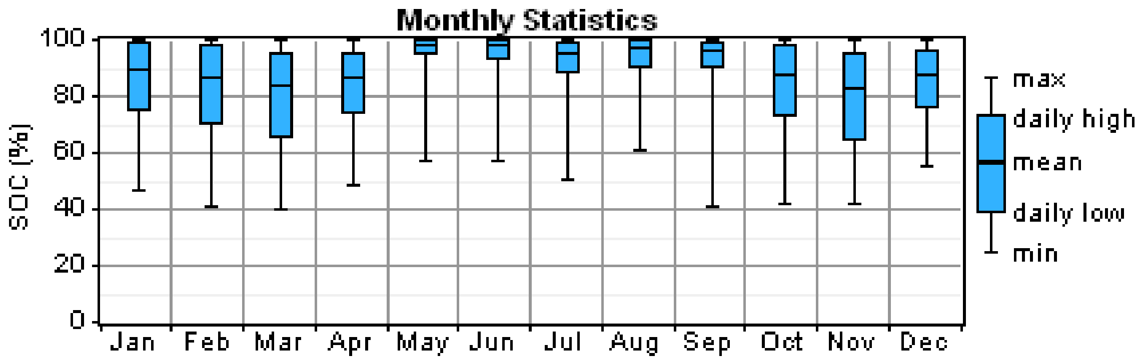
A3.8 Battery

Quantity	Value
String size	20
Strings in parallel	2
Batteries	40
Bus voltage (V)	120

Quantity	Value	Units
Nominal capacity	86.4	kWh
Usable nominal capacity	60.5	kWh
Autonomy	1.94	hr
Lifetime throughput	43,000	kWh
Battery wear cost	0.252	$/kWh
Average energy cost	0.237	$/kWh

Quantity	Value	Units
Energy in	9,294	kWh/yr
Energy out	7,908	kWh/yr
Storage depletion	7.89	kWh/yr
Losses	1,378	kWh/yr
Annual throughput	8,577	kWh/yr
Expected life	5.01	yr





A3.9 Converter

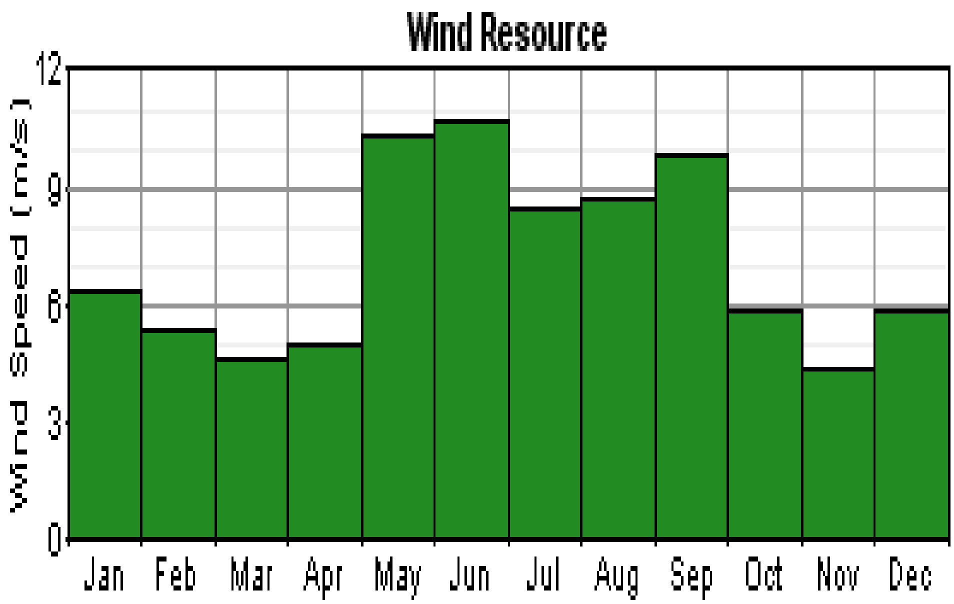
Quantity	Inverter	Rectifier	Units
Capacity	16.0	16.0	kW
Mean output	0.8	1.1	kW
Minimum output	0.0	0.0	kW
Maximum output	9.7	4.3	kW
Capacity factor	5.1	6.6	%

Quantity	Inverter	Rectifier	Units
Hours of operation	1,789	4,942	hrs/yr
Energy in	7,908	10,326	kWh/yr
Energy out	7,117	9,294	kWh/yr
Losses	791	1,033	kWh/yr

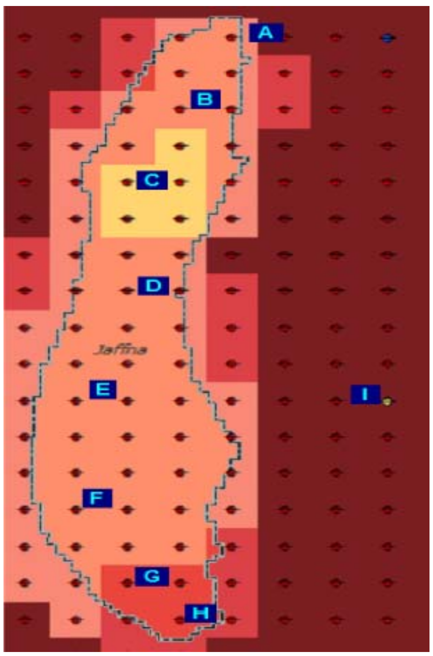
A3.10 Emissions

Pollutant	Emissions (kg/yr)
Carbon dioxide	74,382
Carbon monoxide	184
Unburned hydocarbons	20.3
Particulate matter	13.8
Sulfur dioxide	149
Nitrogen oxides	1,638

Annex 4: Wind resources in the Eluvaithivu Island



Source: Data predicted from CEB's Mannar hourly wind data @30m height



Location	Mean Annual Average Wind Speed @20m height (m/s)	Mean Annual Average Wind Power Density
A	6.77	268
B	6.61	249
C	6.50	237
D	6.57	246
E	6.73	265
F	6.87	282
G	7.05	307
H	7.33	345

Source: Satellite data from M/s.Trueskill Energen (Pvt) Ltd, Bangalore

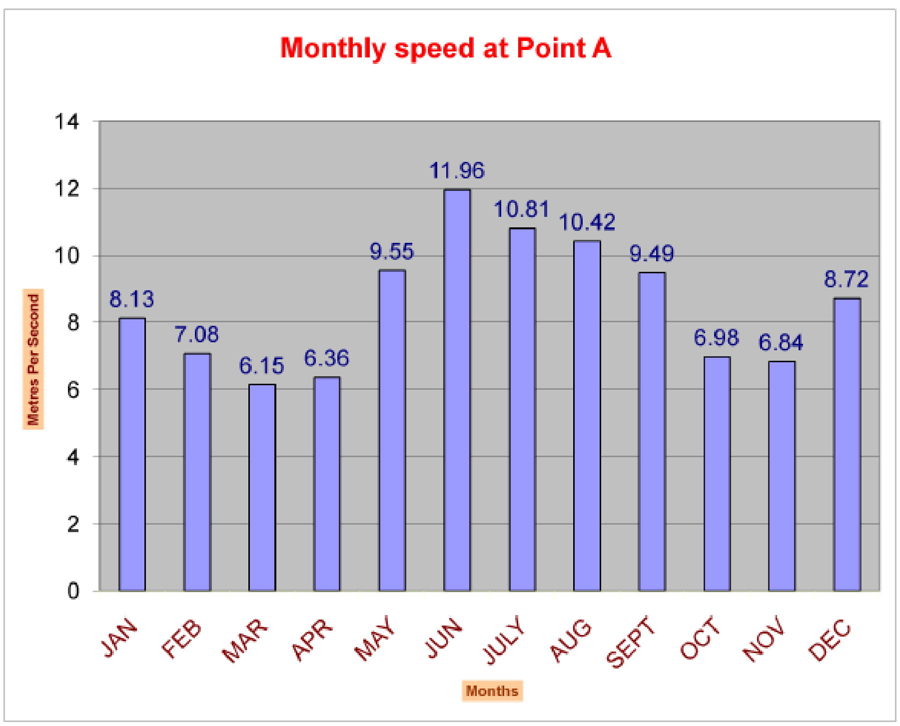
- Annual average wind speed in the Island ~ 7m/s @30m height.

PARAMETERS	A	B	C	D	E
Longitude	79.814	79.812	79.8102	79.81	79.8085
Lattitude	9.71476	9.711	9.7074	9.7021	9.6967
Elevation - Metres	General elevation at site varies from 4 metres to 12 + metres				
Roughness	General roughness at site is around 0.300				
Mean annual wind speed - Metres/Sec-@20 m height	6.772	6.607	6.499	6.57	6.73
Mean annual Power Density-@20 m height	267.7	248.88	237.2	246	264.8
PARAMETERS	**F**	**G**	**H**	**Predominant Power sectorwise at Point I - 79.8194 / 9.69676**	
Long / Lat	79.808/9.6913	79.810/9.687	79.812/9.685		
Mean annual wind speed - Metres/Sec-@20 m height	6.87	7.05	7.33	Sect 10=40.5	Sect 2=10.5
Mean annual Power Density-@20 m height	282	307	345	Sect 11=21	Sect 3=8.3

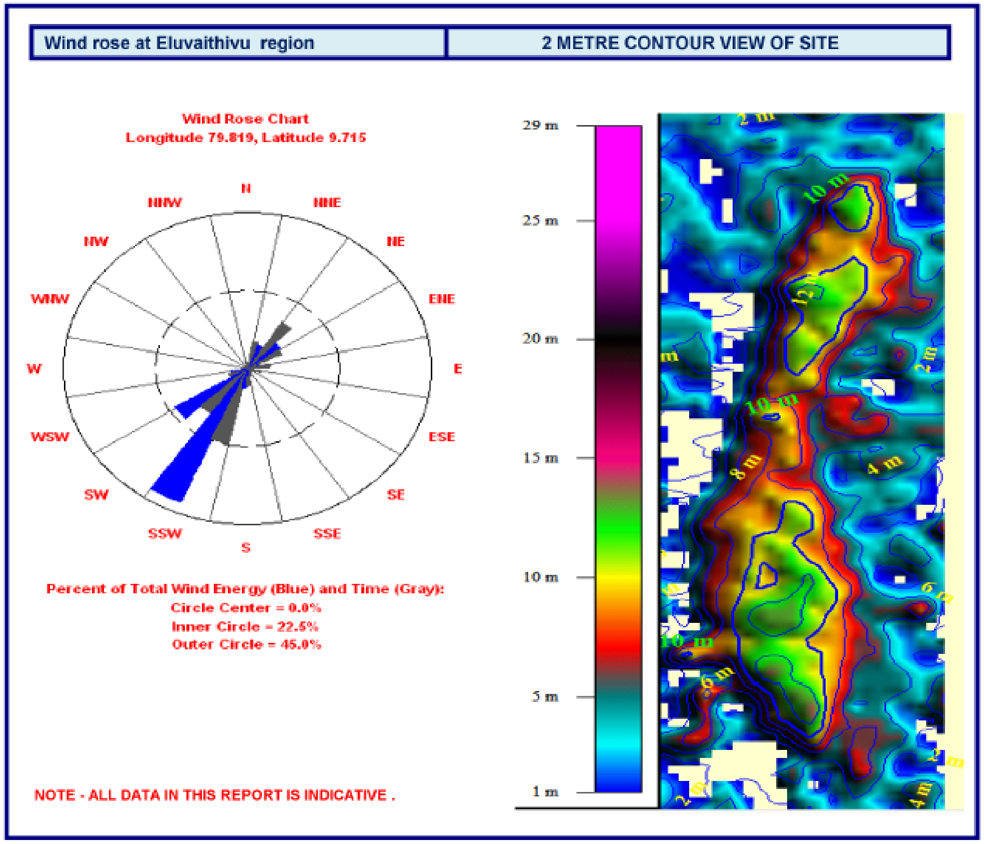
Monthly Speed at 60 m Height	At Point I 79.819 / 9.696	Temperature Annual = 26.9 deg C	Daily Solar radiation = Avg 5.48 Kwh / sq met /day	Nasa Surface Meteorology at 79.811 / 9.698 - For Temp and Radiation	
JAN	8.125	25.5	5		
FEB	7.082	26	5.98		
MAR	6.1489	27.1	6.69		
APR	6.364	27.4	6.31		
MAY	9.553	27.7	5.97		
JUN	11.961	27.8	5.61		
JULY	10.808	27.6	5.49		
AUG	10.424	27.6	5.62		
SEPT	9.487	27.2	5.67		
OCT	6.981	26.7	4.82		
NOV	6.839	26.3	4.22		
DEC	8.717	26	4.38		

Weibull K generally across site is 2.65 to 2.69				

Monthly Speed at 60 m Height - For Point A - shown as a graph



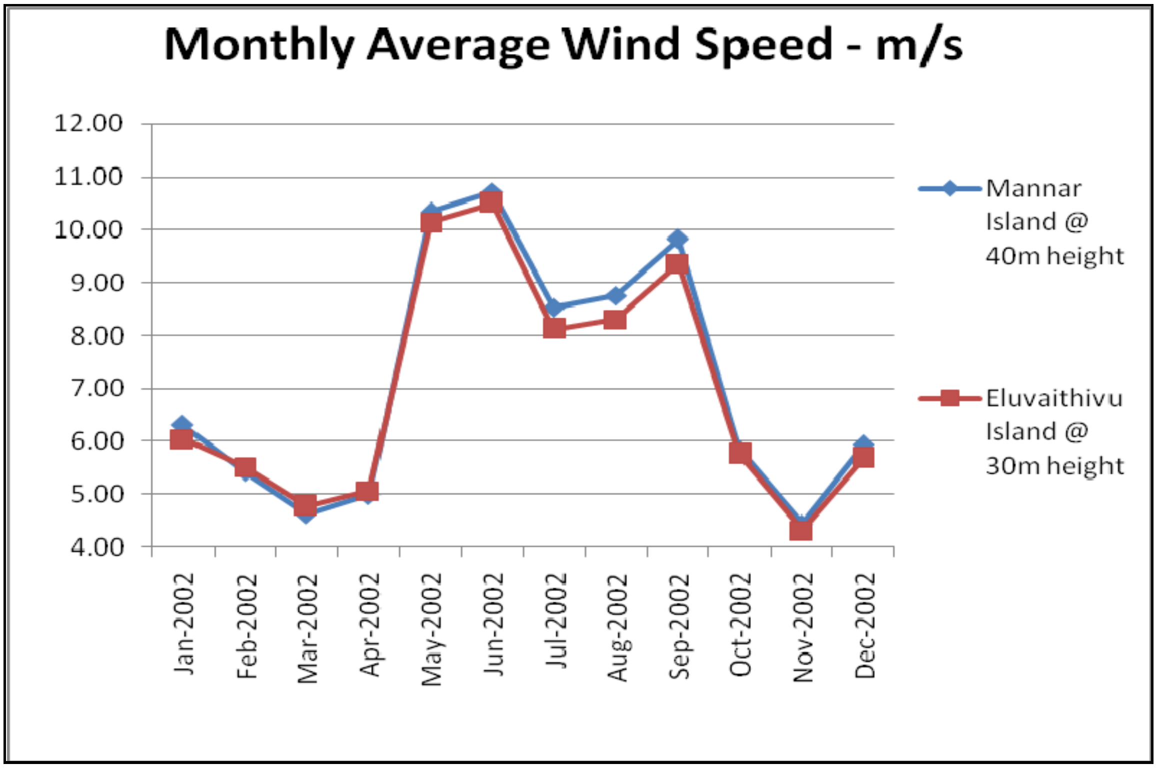
Source: Satellite data from M/s.Trueskill Energen (Pvt) Ltd, Bangalore



Source: Satellite data from M/s.Trueskill Energen (Pvt) Ltd, Bangalore

Comparison of measured wind data at nearest CEB's wind measuring station with Satellite wind data

Month	Monthly Average Wind Speed - m/s				
	Mannar Island	**Eluvaithivu Island**	**Wind data used in Homer Model****	**Saterlite data @ Eluvaithivu**	**Saterlite data @ Eluvaithivu**
	@ 40m height	@ 30m height	@ 40m height	@ 20m height	@ 60m height
Jan-2002	6.31	6.05	**6.31**		**8.13**
Feb-2002	5.43	5.52	**5.43**		**7.08**
Mar-2002	4.63	4.78	**4.63**		**6.15**
Apr-2002	4.99	5.07	**4.99**		**6.36**
May-2002	10.33	10.15	**10.34**		**9.55**
Jun-2002	10.72	10.51	**10.72**		**11.96**
Jul-2002	8.54	8.12	**8.41**		**10.81**
Aug-2002	8.75	8.31	**8.75**		**10.42**
Sep-2002	9.82	9.36	**9.78**		**9.49**
Oct-2002	5.85	5.76	**5.85**		**6.98**
Nov-2002	4.44	4.31	**4.44**		**6.84**
Dec-2002	5.93	5.68	**5.93**		**8.72**
Annual Average	**7.15**	**6.97**	**7.13**	**7.33**	**8.54**


Monthly Average Wind Speed - m/s
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
Jan-2002
Feb-2002
Mar-2002
Apr-2002
May-2002
Jun-2002
Jul-2002
Aug-2002
Sep-2002
Oct-2002
Nov-2002
Dec-2002
Mannar Island @ 40m height
Eluvaithivu Island @ 30m height

Annex 5: Performance analysis of Wind turbines and Solar PV for the Eluvaithivu island project

List if Wind Turbines considered for analysis

More than 200 wind turbines from different manufacturers were studied and following were shortlisted based on price, performance, reliability, suitability and reputation etc.

No	Model	Capacity (kW)	Rated Speed (m/s)	Manufacturer
1	Skystream 3.7	2.4kW (1Ph AC 240V)	13.0	Southwest Wind Power Inc (USA) www.windenergy.com
2	Whisper 500	3kW (1Ph AC 240V & 48V DC)	10.5	Southwest Wind Power Inc (USA) www.windenergy.com
3	Bergey Excel-R	7.5kW (48V DC)	13.5	Bergey Wind Power (USA) www.bergey.com
4	Bergey Excel-S	10kW (1Ph AC 240V)	15.5	Bergey Wind Power (USA) www.bergey.com
5	AR-7500	7.5kW (1Ph AC240V & 48V DC)	9.7	Vaigunth Ener Tek (P) Ltd, (India) www.v-enertek.com
6	Gaia-wind	11kW (3Ph AC 400V 50Hz)	9.5	Gaia Wind Limited (Denmark/UK) www.gaia-wind.co.uk, www.gaia-wind.com
7	AOC 15/50	50kW (3Ph AC 480V 50Hz)	13.0	Atlantic Orient Canada/MaManna Renewable Energy www.atlanticorientcanada.ca aoc.mamanna.com
8	WES18	80kW (3Ph AC 400V 50Hz)	12.5	Wind Energy Solutions (Netherland/Canada) www.windenergysolutions.nl
9	Northwind 100	100kW (3Ph AC 480V 50/60Hz)	14.5	Northern Power System (USA) www.northernpower.com
10	WES30	250kW (3Ph AC 400V 50Hz)	12.5	Wind Energy Solutions (Netherland/Canada) www.windenergysolutions.nl

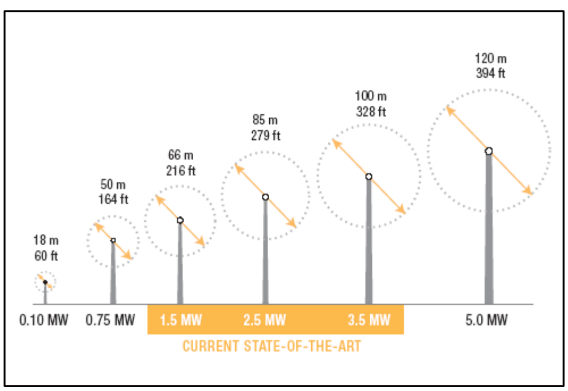


Table 4. Five Largest Manufacturers in 2009, in kW Sold

Company	Country	kW Sold Worldwide
Southwest Windpower	U.S. (AZ)	11,700
Northern Power Systems	U.S. (VT)	9,200
Proven Energy	U.K. (Scotland)	3,700
Wind Energy Solutions	Netherlands	3,700
Bergey WindPower Co.	U.S. (OK)	2,100

Source: American Wind Energy Association Annual Report - 2010

Price & performance of the Wind Turbines

No	Model	Capacity (kW)	Rated Speed (m/s)	Price (US$)	Free Stand Tower Height (m)	Annual Energy Output @6.5m/s (kWh)
1	Skystream 3.7	2.4kW	13.0	15,000	15	5,000
2	Whisper 500	3kW	10.5	15,000	15	8,500
3	Bergey Excel-R	7.5kW	13.5	45,000	30	15,500
4	Bergey Excel-S	10kW	15.5	55,000	30	13,700
5	AR-7500	7.5kW	9.7	20,000	30	23,000
6	Gaia-wind	11kW	9.5	80,000	18	40,300
7	AOC 15/50	50kW	13.0	120,000	24	105,400
8	WES18	80kW	12.5	350,000	30	141,500
9	Northwind 100	100kW	14.5	500,000	37	174,250
10	WES30	250kW	12.5	750,000	30	400,000

Price & performance of the Solar PV

No	Model	Capacity (kW)	Avg. Solar Radiation (Hours/Day)	Price (US$)	Free Stand Tower Height (m)	Annual Energy Output (kWh)
1	Solar PV	15kW	5.5	80,000	2	25,000

Basic COE analysis of different WTG's and Solar PV

No	Model	Initial Cost (US$)	Life time (Yrs)	Energy Production @6.5m/s /Yr in kWh	Total Energy Production during Life span in kWh	COE /($/kWh)
1	Skystream 3.7	15,000	20	5,000	100,000	0.15
2	Whisper 500	15,000	15	8,500	127,500	0.12
3	Bergey Excel-R	45,000	30	15,500	465,000	0.10
4	Bergey Excel-S	55,000	30	13,700	411,000	0.13
5	AR-7500	20,000	10	23,000	230,000	0.09
6	Gaia-wind	80,000	25	40,300	1,007,500	0.08
7	AOC 15/50	120,000	20	105,400	2,108,000	0.06
8	WES18	350,000	30	141,500	4,245,000	0.08
9	Northwind 100	500,000	30	174,250	5,227,500	0.10
10	WES30	750,000	30	400,000	12,000,000	0.06
11	Solar PV 15kW	80,000	25	25,000	625,000	0.13

It is obvious from above analysis that Solar PV is not competitive with the WTG's at windy areas where annual average wind speed is 6.5m/s or above. This argument is valid for the Grid connected applications.

But for the off-grid applications it should be noted that nearly 30% of the energy generated by the WTG's (High penetration systems) wasted as heat through dump loads during high windy seasons. But for the Solar PV, nearly uniform energy generation throughout the year. Also annual maintenance cost is very less for Solar PV. In this point of view Solar PV becomes competitive in some occasions. This issue has to be considered based on site condition, energy usage (including excess energy) and level of renewable energy penetration etc at the design stage.

Eg: Gaia wind (11kW) = US$80,000 = 40,300kWh/Yr x 0.7 = 28,200kWh/Yr (Useful Energy)
Solar PV (15kW) = US$80,000 = 25,000kWh/Yr (Useful Energy)

Equivalent WTG's and Solar PV based on price & performance

No	Model	Equivalent Model	Equivalent Model	Equivalent Model
1	Whisper 500	1.5 x Skystream 3.7		
2	Bergey Excel-R	4 x Skystream 3.7		
3	Gaia-wind	7 x Skystream 3.7	2 x Bergey Excel-R	
4	WES18	25 x Skystream 3.7	9 x Bergey Excel-R	4.5 x Gaia-wind
5	Solar PV 15kW	5 x Skystream 3.7	1.5 x Bergey Excel-R	0.6 x Gaia-wind
6	WES18	(3 x Gaia-wind) + (1 x Solar PV 15kW)		
7	WES18	(2 x Gaia-wind) + (2 x Solar PV 15kW)		

Summary

There are three options available in the view of selecting RE sources to make high penetration systems.

I. **1No. of WES18 80kW Wind Turbine Generator**

II. **3Nos. of Gaia-wind 11kW Wind Turbine Generator with 15kW Solar PV**

III. **2Nos. of Gaia-wind 11kW Wind Turbine Generator with 10kW Solar PV**

What "HOMER" Says?

All three options are fed to the homer and let homer to select the best options. The homer output is given as follows;

Data: Annual Average Wind Speed- 7.0m/s, Diesel fuel price – 0.9 US$/Liter and Village load 500kWh/Day. Annual demand is 182,500kWh/Yr.

Opt.	WES18 (kW)	Gaia 11 (kW)	Solar PV (kW)	DG-L (kW)	DG-S (kW)	Converter (kW)	Battery (Trojan L16P) (Nos)	COE ($/kWh)	Renew. Fraction (%)	Excess Energy (kWh/Yr)	Capital RE Equipment Cost ($)
1	-	-	-	45kW	15 kW	16 kW	40	0.48	0%	0	61,000
2	-	1 (11kW)	-	45kW	15 kW	16 kW	40	0.45	25%	315	151,000
3		2 (22kW)	-	45kW	15 kW	16 kW	40	0.43	46%	16,350	231,000
4	-	3 (33kW)	-	45 kW	15 kW	16 kW	40	0.44	61%	43,700	311,000
5	-	2 (22kW)	10kW	45 kW	15 kW	16 kW	40	0.44	53%	23,300	281,000
6	-	2 (22kW)	15kW	45 kW	15 kW	16 kW	80	0.45	55%	27,900	311,000
7	-	3 (33kW)	10kW	45 kW	15 kW	16 kW	40	0.46	66%	52,700	371,000
8	1 (80kW)	-	-	45kW	15 kW	-	-	0.57	67%	121,900	395,000
9	1 (80kW)	-	-	45kW	15 kW	16 kW	40	0.50	71%	103,600	421,000
10	1 (80kW)	-	10kW	45kW	15 kW	16 kW	40	0.52	74%	112,300	471,000
11	-	-	20kW	45kW	15 kW	16 kW	40	0.50	18%	1,100	171,000
12	-	-	30kW	45kW	15 kW	16 kW	40	0.52	25%	5,650	221,000

Additional US$70,000 has to be added for supporting activities in the above installation. All the above costs exclude profit margins for external contract.

Option-1 is diesel only system and at-least this to be done. Option-9 is the best if considered there is no initial capital problem and excess energy is used in productive way. Option-5 is the next high priority option with reasonable investment.

Summary

Item	Renewable Energy Fraction (%)	Cost (US$)	Cost Factor	Wind Turbine Generator Selection
1	25 % – 30%	150,000	x	1 Gaia-Wind 11kW
2	50% - 60%	300,000	2x	2 - 3 Gaia-Wind 11kW
3	75% - 80%	450,000	3x	1 WES 18 80kW

Annex 6: List of equipments considered for the Homer software analysis

Wind Turbine Generators (Marine Version)

I. Skystream 3.7 (2.4kW) - USA

II. Whisper 500 (3kW) - USA

III. Bergey Excel-R (7.5kW) / Bergey Excel-S (10kW) - USA

IV. AR-7500 (7.5kW) - India

V. Gaia-wind (11kW) – Denmark/UK

VI. AOC 15/50 (50kW) – USA/Canada

VII. WES18 (80kW) – Netherland/Canada

VIII. Northwind 100 (100kW) - USA

Hybrid controller with Converter (Marine Version)

I. Sun Energy three phase – Hybrid (AES-H40) – USA

II. Optimal Power Solutions (HPC-3P-1D-60K-230-50-240-25-PWM) –Australia/India

III. Leonics (MTP-414F) – Thailand

IV. Schneider (XW Series) – USA

V. Ingeteam (Ingecon Hybrid) – Spain

Sealed Type Batteries

I. Trojan L16P(6V, 360Ah) - USA

II. Trojan T-105(6V, 225Ah) - USA

III. USB US-305 - USA

Diesel Generators - (Sound Proof/ Marine Version)

I. Caterpillar Power Generators - USA

II. Cummins Power Generators – UK

III. Kirloskar Power Generators – India